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

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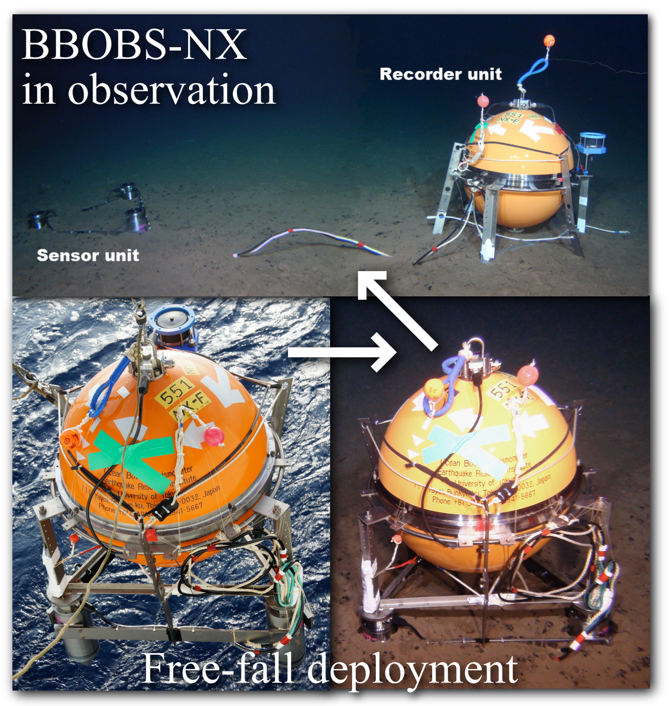
Summary

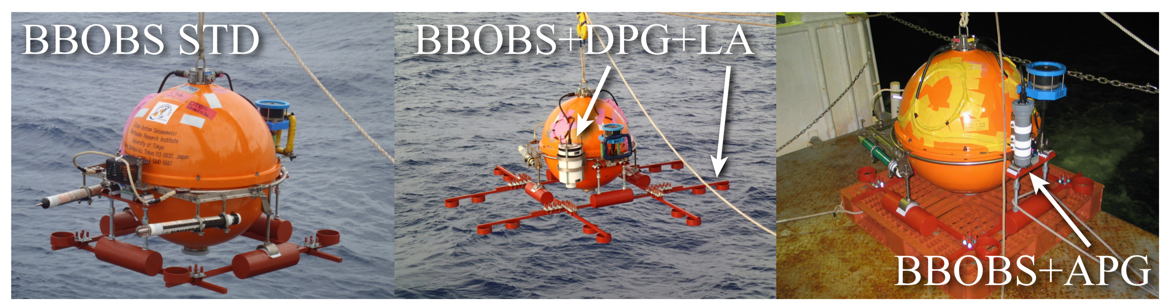
The broadband ocean bottom seismometer (BBOBS) and its new generation system (BBOBS-NX) have been developed in Japan, and we performed several test and practical observations to create and establish a new category of the ocean floor broadband seismology, since 1999. Now, the data obtained by our BBOBS and BBOBS-NX is proved to be adequate for broadband seismic analyses. Especially, the BBOBS-NX can obtain the horizontal data comparable to land sites in longer periods (10 s –). Moreover, the BBOBST-NX is in practical evaluation for the mobile tilt observation that enables dense geodetic monitoring at the sea floor.

The BBOBS-NX system is a powerful tool, although, it has intrinsic limitation of the ROV operation required. If this system can be used without the ROV, like as the BBOBS, it should lead us a true breakthrough of ocean bottom seismology. Hereafter, the new autonomous BBOBS-NX is noted as NX-2G in short. The main problem to realize the NX-2G is a tilt of the sensor unit on landing, which exceed the acceptable limit (±8 °) in about 50% of deployments. As we had no evidence at which moment and how this tilt occurred, we tried to observe it during the BBOBST-NX landing in 2015 by attaching a video camera and an acceleration logger. The result shows that the tilt on landing was determined by the final posture of the system at the penetration into the sediment, and the large periodic tilting more than ±10 ° was observed in descending. The function of the NX-2G system is based on 3 stage operations as shown in the schematic image at the right panel. The glass float is aimed not only to obtain enough buoyancy to extract the sensor unit, but also to suppress the periodic tilting of the system in descending.

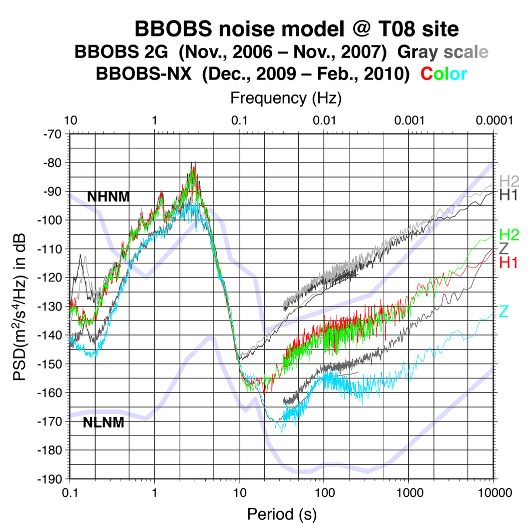
In Oct. 2016, we made the first in-situ test of the NX-2G system with a ROV. It was dropped from the sea surface with the video camera and the acceleration logger. The ROV was used to watch the operation of the system at the seafloor. The landing looked well and it was examined from the acceleration data. As the maximum tilt in descending was about ±2.5°, the glass float effectively suppressed the periodic tilting. The extraction of the sensor unit was also succeeded with the total buoyancy of about 75 kgf within about 2.5 minutes. As the final step experiment, the one-year-long observation of this NX-2G system has been started in this April with the BBOBS, to obtain simultaneous data for the noise level evaluation. The recovery is planned in September 2018.

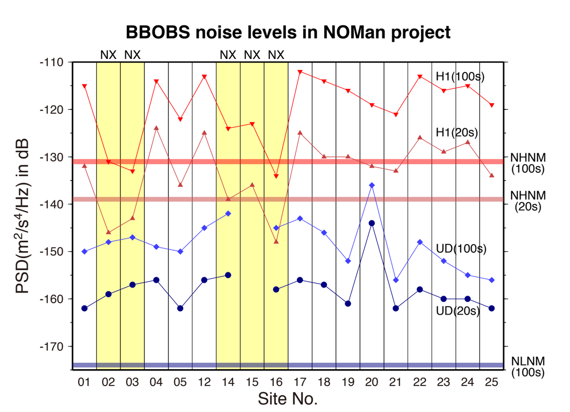
Improvements of BBOBS : 2005 – 2012





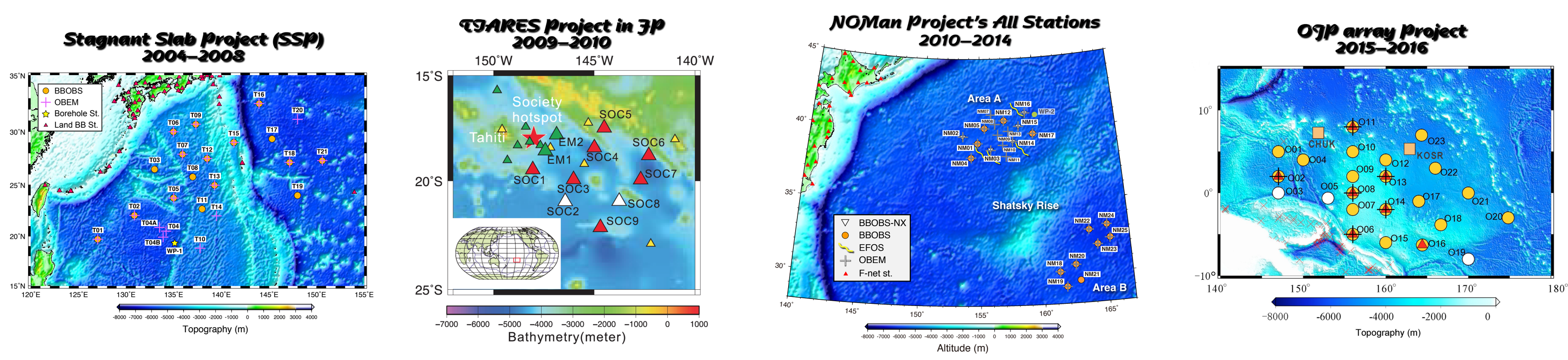
The first BBOBS had been developed since 1999, and it has been improved continuously during use in practical array observations ([1], [2]). The BBOBS with a long anchor (LA) reduces the vertical noise level, too [3]. By attaching the DPG [4] or the APG [5] to the BBOBS, we can observe more useful signals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



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[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.

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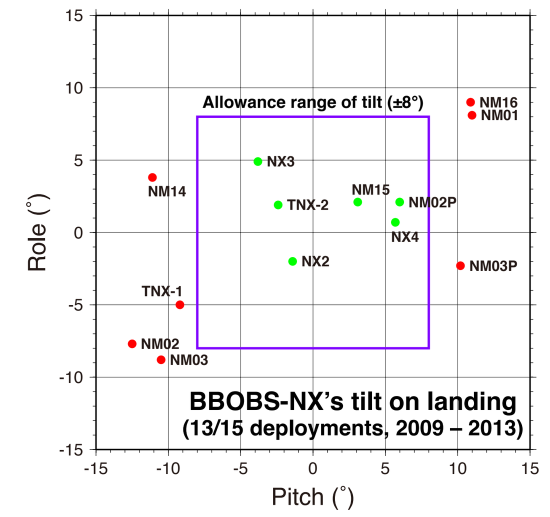
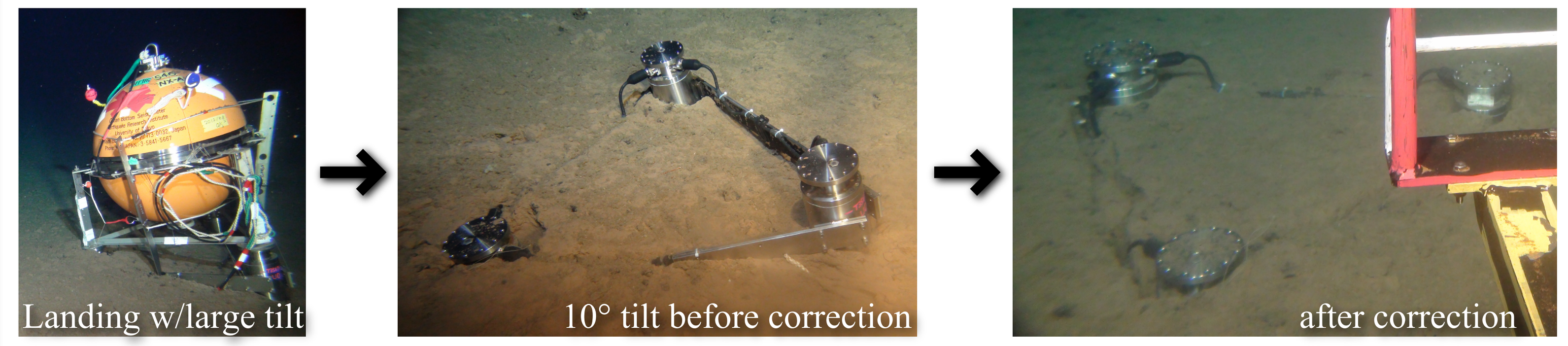
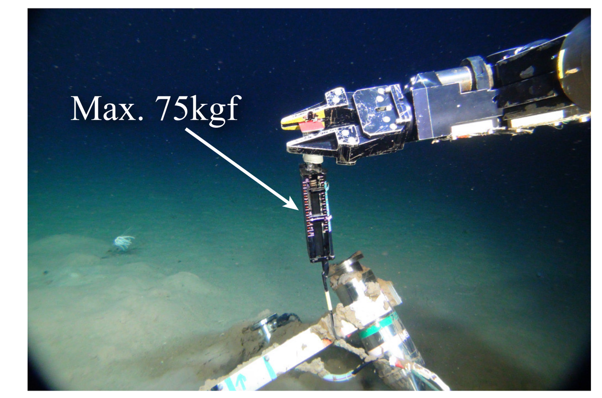
Preparation toward NX-2G : 2012 – 2015



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.

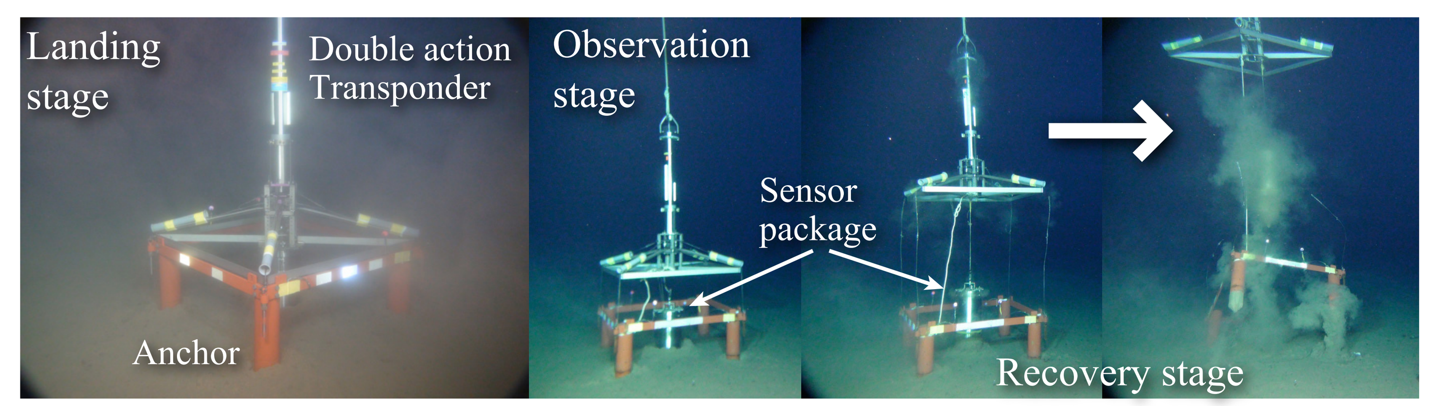
The special CMG sensor (360 s) used in the sensor unit allows operation up to ±8 ° inclination, but about half cases of tilt on landing exceeded this limit (left graph). In the BBOBS-NX operation with the ROV, this tilt can be corrected as shown in following photos by using the skid of the ROV, and this 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 since 2015.





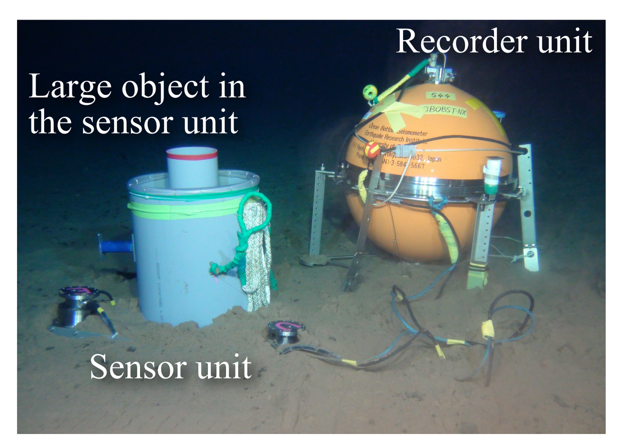
The amount of required force to extract the sensor unit penetrated into the sediment was measured at the seafloor by using original spring weight scale at several sites, such as deep sea basin and trench slope. It was ranged from 60 to 80 kgf according to the different type of sedimentations. The weight 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.

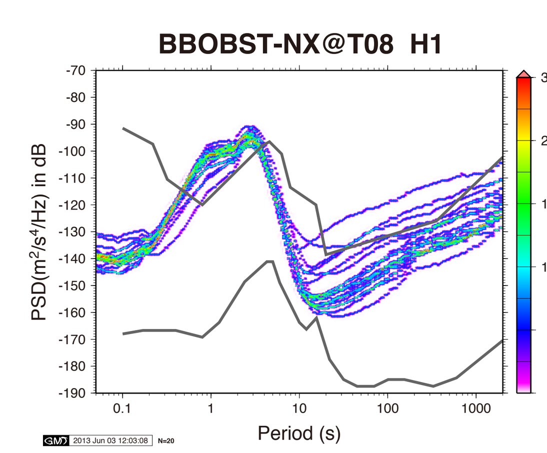
New style Ultra-Deep OBS tested in 2012 – 2013

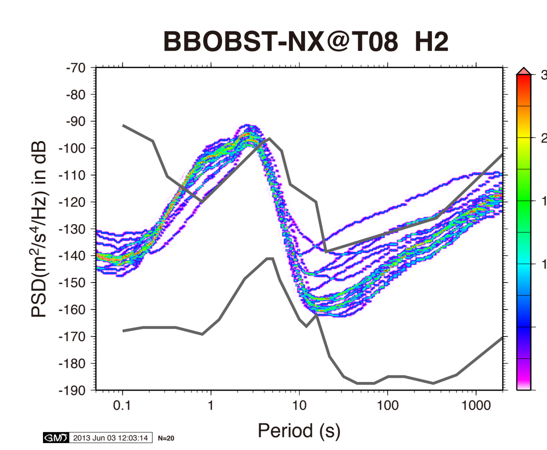


A similar concept system with the NX-2G (refer the right panel) had been tested as the NUDOBS in 2012. It realized the 3 stage operation by using a two step action mechanical transponder that was newly developed for it. The NUDOBS is designed to be deployed up to 10000 m depth without using underwater cables. This system was deployed at the triple junction off Boso Peninsula (9200 m depth) in 2013 with good status into the observation stage, but it did not answer at the recovery in 2014.

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



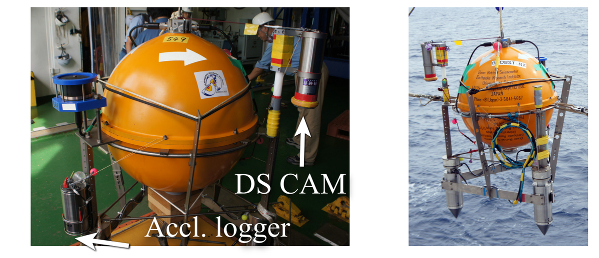


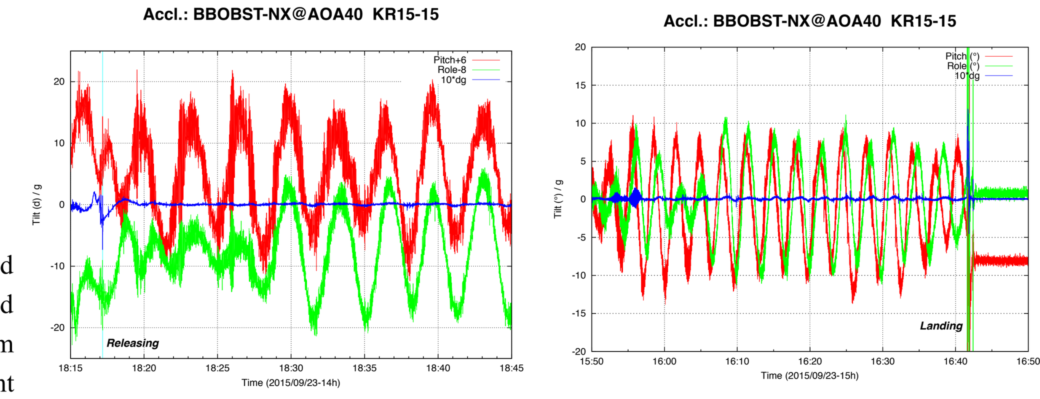


To evaluate the effect in noise levels by placing the recorder unit, Ti sphere housing (D=650mm) and a large object close to the sensor unit of the BBOBS-NX, about 2 months long test observation was performed at the T08 site (refer map of the SSP in the left panel). Such large objects could cause the 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.

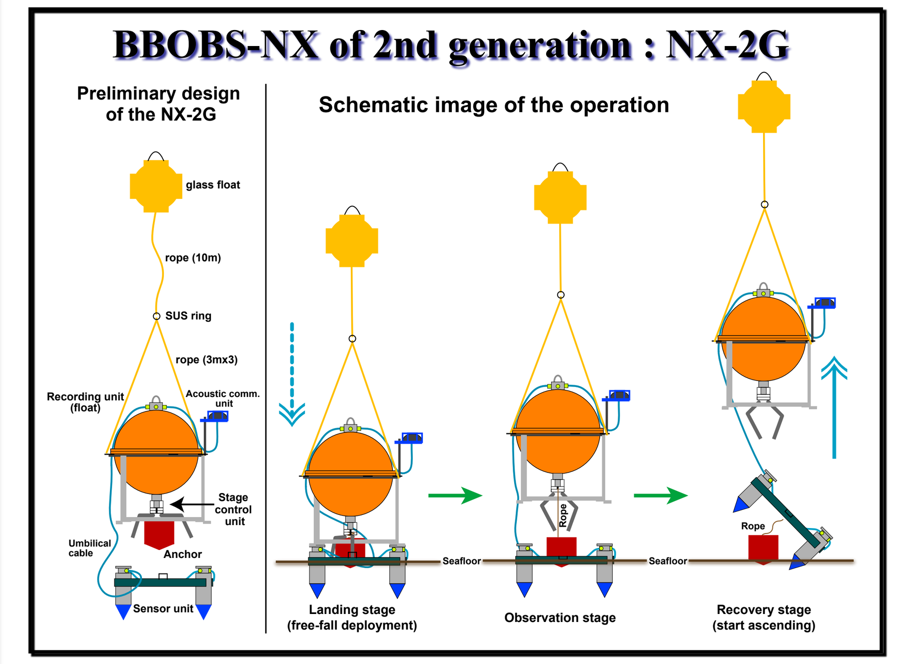
The result (right graphs) shows almost same noise levels in the horizontal component compared with the previous test observation of the BBOBS-NX placing the recorder unit about 2 m away from the sensor unit. It is expected that if the vibrating object was weakly coupled with the sediment, the induced 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.

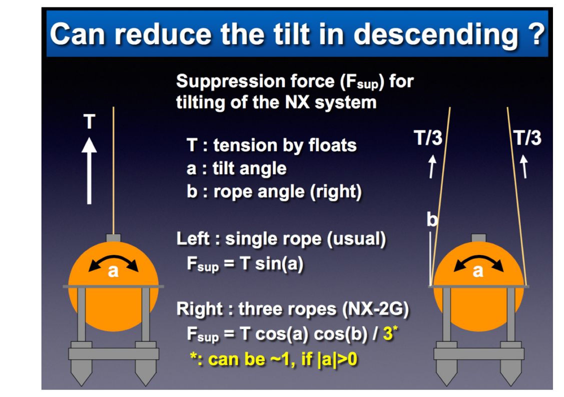
Cause and fix of the tilt on landing : 2015 – 2016





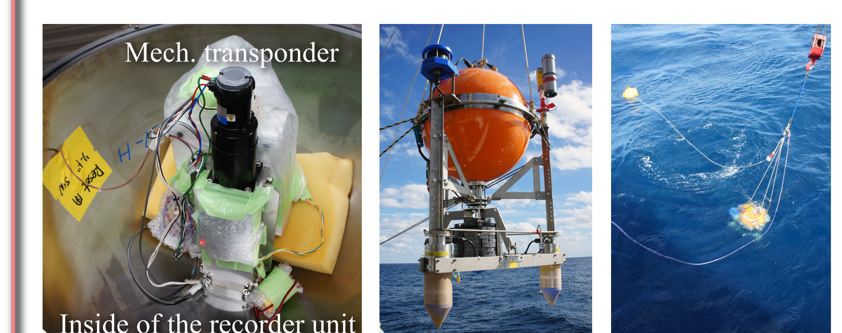
By using original acceleration logger and deep-sea CAM, we observed when and how the tilt on landing occurred in 2015 when we deployed the BBOBST-NX. A periodic tilting started when it was released from the sea surface, and the final posture seemed to determine the tilt (right two graphs).

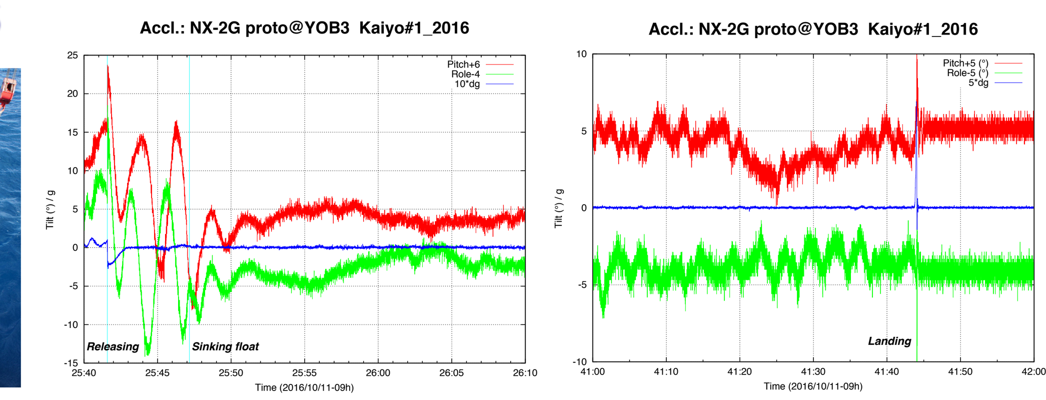


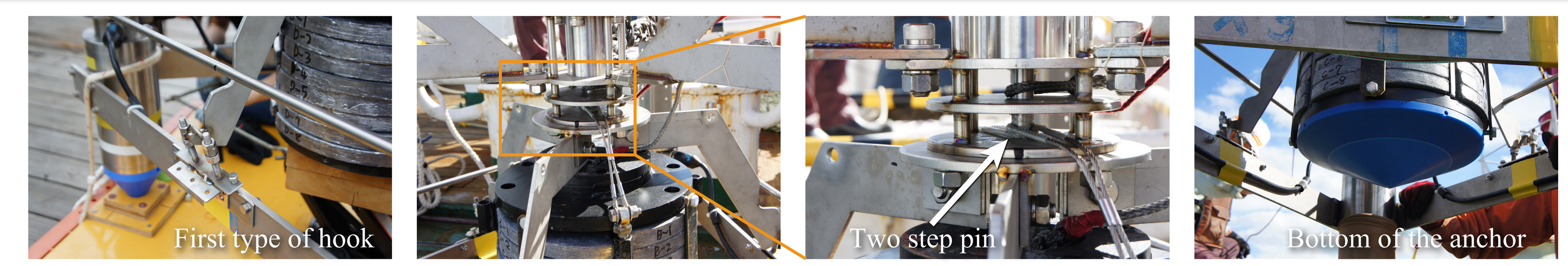


As we should add some floats to extract the sensor unit with the NX-2G, we consider to use this buoyancy for suppression the periodic tilting also. This idea was examined at the test in 2016, and it seemed working well as shown in two graphs below. Soon after the releasing from the sea surface, the NX-2G started the tilting. But, when the float started to sink, tension of three ropes (lower left photo) 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.

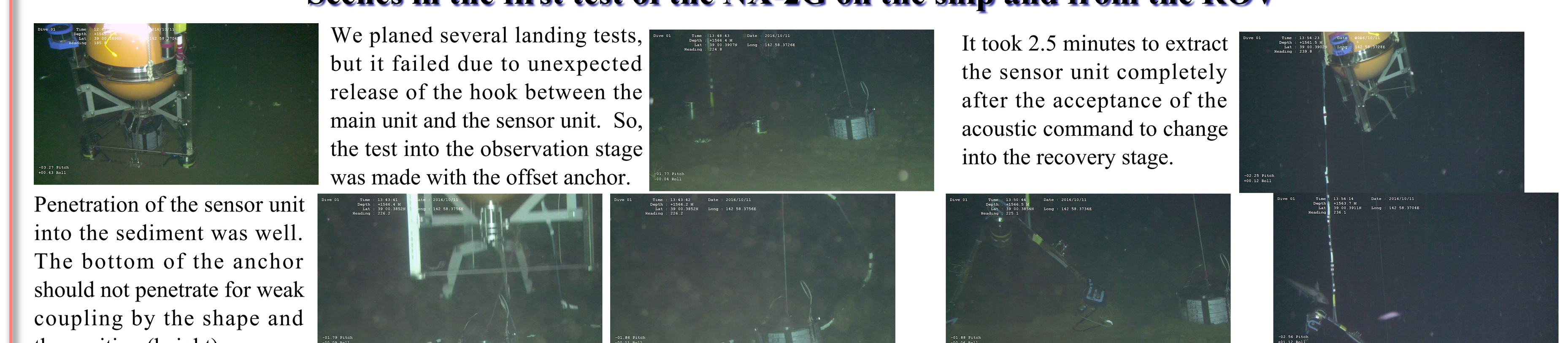
The first test of the NX-2G in October 2016







Scenes in the first test of the NX-2G on the ship and from the ROV

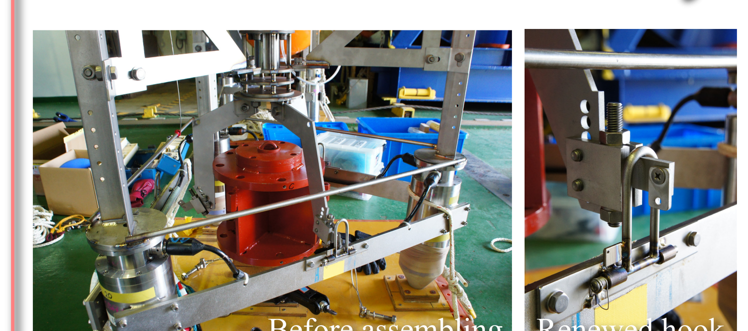


We planed several landing tests, but it failed due to unexpected release of the hook between the main unit and the sensor unit. So, the test into the observation stage was made with the offset anchor.

It took 2.5 minutes to extract the sensor unit completely after the acceptance of the acoustic command to change into the recovery stage.

Penetration of the sensor unit into the sediment was well. The bottom of the anchor should not penetrate for weak coupling by the shape and the position (height).

In-situ test of the NX-2G : 2016 – 2017 ~



The first long-term deployment of the NX-2G has started in this April instead of the BBOBST-NX deployment due to unavailability of the ROV by bad weather forecast. As this observation is aimed to evaluate the systematic noise level and the function among stages, the recovery is designed to use the ROV and will be performed in Sep. 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. 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.

The first launch of the NX-2G in April 2017