Installation of the multi-disciplinary VENUS observatory at the Ryukyu Trench using Guam-Okinawa geophysical submarine cable

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Abstract. A multi-disciplinary VENUS (Versatile Eco-monitoring Network by Undersea-cable System) observatory was installed at the depth of 2,170 meters on the slope of the Ryukyu Trench. It equips seven geophysical instrument groups. Prior to the installation of the VENUS multi-disciplinary ocean bottom (MDOBO) observatory, an ocean-bottom telemetry system, which has functions to supply electrical power to the MDOBO, and the submarine coaxial cable were installed at ocean bottom. The installation of the multi-disciplinary ocean bottom observatory was done by use of deep-towing unit and ROV *Kaiko-10K*. During the period of August- September 1999, seven instrument groups of MDOBO were deployed at the target position, at 80-1000 meter distances from the telemetry system, with several meters allowances using a deep-towing unit. To install the instrument at the exact location, the mother ship of deep-towing unit was precisely navigated. The extension cables were also dropped from the deep-towing unit. The ROV *Kaiko-10K* extended multi-conductor extension cables from instrument units towards the ocean-bottom telemetry system and connected them to undersea mateable connectors on the junction box. The MDOBO collected one and half month records. Some useful data were observed since the installation.

1. Introduction

It has been widely recognized that studies of temporal variations are extremely important since geophysical phenomena have episodic natures and some phenomena such as earthquake occurrence or submarine volcanism require real-time observation. One of the best technologies to achieve real time and long-time observations is the use of submarine cables. The use of new fiber-optic submarine cables is costly. Another kind of submarine cable is the coaxial cable, which can provide electrical power and real-time telemetry. By reuse of coaxial submarine cable resource, a real-time geophysical observatory on the deep-sea floor can be realized by high reliability (e.g., Nagumo and Walker, 1989; Kasahara et al., 1995). By the use of old coaxial submarine cable TPC-1 (Trans Pacific Cable-1), an ocean bottom seismometer was installed on the forearc slope of the Izu-Bonin Trench by the GeO-TOC project, showing effectiveness to realize real-time ocean bottom measurement by reasonable cost (Kasahara et al., 1998a,b). Although this deployment was based on well-developed method in the submarine cable works, it is difficult to add some branches from the main cable if multi-sensors are required within nearby-locations.

The TPC-2 submarine cable was the second Japan-US submarine cable constructed in 1976 and it terminated its long commercial service in 1994 due to the replacement by a new generation cable. In 1995, the VENUS (Versatile Eco-monitoring Network by Undersea-cable System) project was created to develop a new multi-disciplinary geophysical station using the TPC-2 cable (Guam Okinawa Geophysical Cable; hereafter GOGC) (Kasahara et al., 2000a). The GOGC passes geophysically important regions and it is routed from the Mariana Trough to the mid-Philippine Sea plate to the Ryukyu Trench. These areas contain seismically very active subduction zone and a rifting back-arc basin. A multi-disciplinary ocean-bottom observatory (hereafter MDOBO) was installed at the Ryukyu Trench during August-October, 1999.

2. VENUS System Description

The TPC-2 (current GOGC) used 1.5"-diameter coaxial cables (SF system) and had 845 voice channels (KDD, 1976). The +1,080 V DC from Okinawa and -1,080 V DC from Guam were supplied to the cables at 136 mA constant current during the commercial use. Voices were transmitted from one end to the other as analog signals by use of 3 kHz carrier band superposed on the high voltage DC. To convert the TPC-2 to a geophysical tool, the cable system was greatly modified on the power supply, the method of communication, and the configuration of the main cable.

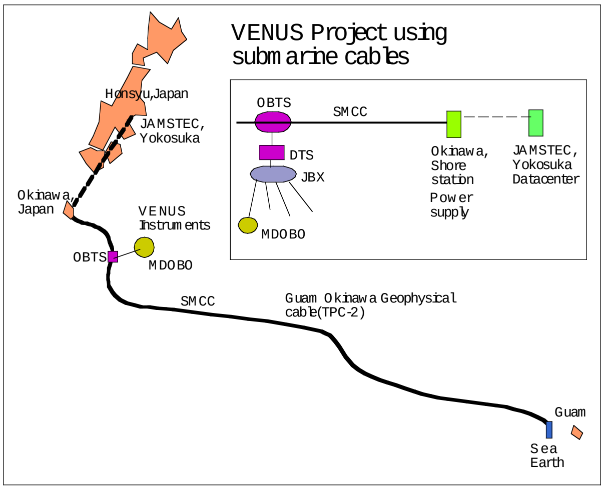

Fig. 1:The VENUS system from the MDOBO to the data center in Yokosuka. MDOBO: Multi-Disciplinary Ocean-Bottom Observatory; JBX: Junction BoX; DTS: Data Telemetry System; OBTS: Ocean Bottom Telemetry System and SMCC: Sub-Marine Coaxial Cable.

The VENUS system comprises the MDOBO, the ocean-bottom telemetry system (hereafter OBTS), sub-marine coaxial cables (hereafter SMCC) of GOGC, and land equipment (Fig. 1). The MDOBO comprises seven bottom sensor groups with one land-based electrical potential measurement system developed by six institutions [1]. Since the details of the VENUS system are described in Kasahara et al (2000a), the outline of the system is described in this paper. The OBTS comprises a data-coupling unit (hereafter DCU), a data-telemetry unit (hereafter DTU) and a junction box (hereafter JBX) developed by the KDD research Laboratory. The methods for deploymental works were developed by the joint efforts of the KDD research Laboratory and JAMSTEC (Japan Marine Science and Technology Center). The cable length of the GOGC is 2,527 km.

The DTU multiplexes multi-component data by TDM (Time Division Multiplexing) and sends them to shore using a 240-kHz-carrier bandwidth. The transmission rate for the multiplexed data is 96 kbps, which is shared by seven instrument groups. If the instrument does not work correctly, users can shut down a malfunctioning unit remotely from a land base.

Each instrument of the MDOBO and the JBX was connected by an eight-conductor extension cable. The data from an instrument transmitted to the JBX through the extension cable by the RS422 protocol. The JBX has nine so-called "ROV (Remotely Operated Vehicle) undersea mateable connectors". The ROV connectors allow units to be plugged in and unplugged on the ocean floor with the assistance of a manned submersible or an ROV.

3. Deployment of whole bottom units

The target site for the MDOBO was selected at 25°44'N and 128°02.5'E at a water depth of 2,200 meters, which is halfway between two repeaters, R139 and R138. The route of the GOGC cables was identified at more than 20 locations by the deep-tow camera of R/V *Yokosuka* in 1998 (Kasahara et al., 2000c). After the careful examination on bottom units, components, and deployment method, the OBTS was successfully installed at the location of 25 44.397 N, 128 03.748' E at the depth of 2,157 meters by the cable ship C/S *Kuroshio-Maru* on August 29, 1999. The location of the OBTS is almost the same as the target site (Fig. 2). At the same time, the hydrophone array and the tsunami gauge were also deployed to the ocean bottom. The tsunami gauge was installed in the same frame with OBTS and the hydrophone array was connected to the OBTS in series. We confirmed that the data from the OBTS, the tsunami gauge and the hydrophone array were correctly transmitted to JAMSTEC.

In middle of September 1999, five instrument sets of the MDOBO other than the hydrophone array and the tsunami gauge were deployed by the deep-towing unit on board of the *R/V Kaiyo* of JAMSTEC , which equipped 6000m-long tethered cables, and two TV cameras, one for watching the bottom and one for watching the ahead. The MDOBO instruments occupied the area with an approximately 1-km radius around the telemetry system as shown in Fig. 2. The positions of instruments were decided by considering the geophysical importance and easiness of deployment. The deep-towing unit also had two releases systems, which could be operated from the *Kaiyo*. It was thought that a precise navigation of deep-towing unit was extremely difficult task because of difficulty to know the precise distance between vehicle and the target, and maneuver the vehicle directly from the mother ship *R/V Kaiyo*. It, however, was carried out with accuracy of approximately three meters by use of ROV homers,

[1] Six institutions (Earthquake Research Institute, JAMSTEC, Hydrographic Department Japan, Geological Survey of Japan, Japan Meteorological Agency and Electronic Technical laboratory) jointly worked.

which could tell us the off-center and the distance to the target. The *Kaiyo* was also navigated by watching the positions of the deep-towing unit and targets on the video-plotter screen and the deep-towing unit was precisely controlled by Kaiyo's speed and heading with several minutes time lags.

For the ocean bottom broad-band seismometer (OBBS), the multi-conductor extension cable with 100m-long on the wooden reel and eight lead weights with 20 kg each were attached to bottom of the deep-towing unit frame, and they were released from the deep-towing unit by one by one (25-44.436'N, 128-03.748'E, 2150m. The OBBS unit was placed at 80 meter north of the bottom telemetry system, within 5-meter distance allowance using a deep-towing unit. The longest extension cables were 1,000 meters long for the three precise-baseline measurement systems (PBMS) and these long cables were extended toward the JBX by the deep-towing unit after the detachment of the measurement unit. The final positions of the PBMS cable drums were less than 40 meters, which were just suitable for the length of the second stage extension cables.

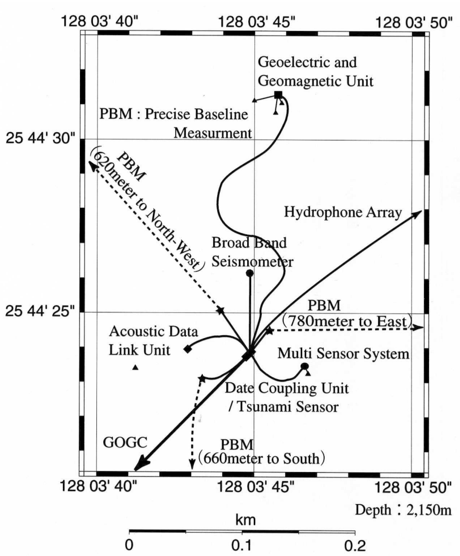

Fig. 2. Geographical arrangements for instruments of MDOBO, DCU and SMCC at the VENUS site.

We also used the ROV *Kaiko-10K*, which was an ROV with capability to dive down to 12,000m deep. The *Kaiko-10K* system comprises a tethered launcher and a shuttle vehicle with 200 meters-long extension cable. The *Kaiko* had missions to find the instruments, extend seven sets of extension cables and connect the undersea meteable connectors (so called ROV connector) of the extension cables and the JBX. The *Kaiko* dived to the target site in the end of September (*KR99-09; dive #128*) During the *Kaiko*-operation, the launcher was kept at 100 meters above the center of the seafloor operation and the shuttle part reached to the seafloor. All the instruments were found to sit correctly at the seafloor. Although each instrument required specific works, each ROV-dive-time was sufficient for the necessary works for each instrument set. Most of instruments excepting the tsunami gauge and the hydrophone array required cable extension works. The *Kaiko* uncoiled the multi-conductor extension cables from each reel and approached slowly to the OBTS. The longest extension cable was 300 meters for the geoelectric and geomagnetic system. The tight and slack situation during the cable extension works was the most difficult one among the *Kaiko* undersea operations. At the OBTS, the manipulators of the *Kaiko* were used to penetrate the male ROV connectors into the receptacles on the JBX (Fig. 3).. Some amount of pelagic sediment was found in the ROV connector cover and it was removed by several operations of plug in-plug out of the ROV connector.

Fig. 3: Photographs of JBX and manipulator operation at the ocean-bottom

A shore station is located in Okinawa. In order to examine the successfulness of each operation, the DC power of 2,900V and 135 mA was supplied to the SMCC, the OBTS and the MDOBO from Okinawa while the *Kaiko* stayed in front of the OBTS. By the power supply to the whole system, we confirmed the correct operation of each instrument. All necessary undersea operations were finished before early October 1999.

The shore-receiving unit (SRU) demodulated signals and sent them to Yokosuka, Japan, using two 64-kbps commercial telephone lines. Some controls of instruments such as level adjustment and clamp-unclamp of the seismic unit were done from Yokosuka. Timing by GPS clock was supplied to each instrument from the shore station. Whole data from the bottom were monitored at Yokosuka. Data from ocean bottom instruments were stored in the data storage at the JAMSTEC.

Some problems arose at two and half months after the deployment of the OBTS. On November 21, 1999, the bottom system was abruptly down. The problem seemed on 24V DC converter in the data-telemetry unit. By two diving cruises of the ROV *Dolphine 3K*, which is the 3,000m-class ROV, and the *Kaiko-10K*, it was found that there were a trace of corrosion on the pressure case of the data-telemetry unit and insufficient insulations on instruments and the OBTS (Kasahara, 2000). The problems seem to be generated during the deployment due to weakness on extension cables and some other causes.

In January 2001, the OBTS, tsunami gauge and the hydrophone array were retrieved to analyze the cause of malfunctioning of the VENUS system using C/S *Kouki-Maru* with assistance of KDDI Co. Ltd. The visual inspection of the OBTS showed serious corrosions on the titanium pressure case of the DTU in contrast to no corrosions on the DCU and the JBX. In addition to some defects on the OBTS, the hydrophone array had some damages on connectors between each sensor and the main electrical cable. It seems that the electrical insulation in such systems was damaged by unknown reasons. The more detail causes will be analyzed by the examination of the retrieved system.

4. Preliminary results

Before November 20, 199, the MDOBO collected one and half month records (Iitaka, et al., 2000; Iwase et al., 2000; Kasahara and Sato, 2000; Kasahara et al., 2000b; Katsumata et al., 2000; Nagaya, 2000; Nakatsuka et al, 2000; Watanabe, 2000). During the observation, an earthquake of Ms= 6.1, which is one of the major aftershocks of the Chichi Earthquake in Taiwan on September 21, 1999 (Ms 7.7), was observed by OBBS (Fig. 4) (Kasahara and Sato., 2000b) However, the noise level of OBBS at period of 100-200 seconds is surprisingly large due to strong influences from the infra-gravity waves currents (Webb, 1998), although it was estimated because the OBBS could not be buried in hard-rock base below the ocean bottom. By comparison with land geomagnetic observation at Kakioka, JMA, 40 days records of geomagnetic field and geo-electric field show good results (Nakatsuka et al., 2000). During the observation period, a magnetic storm on Oct. 20, 1999 was observed. Both geomagnetic and geo-electric showed simultaneous variation.

The multi-sensor system showed that the bottom current was quite high (about 20 cm/s) and the bottom temperature change at depth of 2,200m was 0.1 °C (Iwase et al., 2000) Although the pressure change measured by the tsunami gauge showed semi-diurnal variation suggesting large effects by tidal forces (Katsumada et al., 2000), the bottom temperature variation (Iwase et al., 2000) showed diurnal changes, which are less effected by tidal forces. The PBLM instrument showed a possibility of crustal deformation measurement at the forearc basin with a few centimeters accuracy over 1km distance when measurements were corrected by bottom temperature variations (Nagaya,2000). Those data are being analyzed.

5. Conclusions

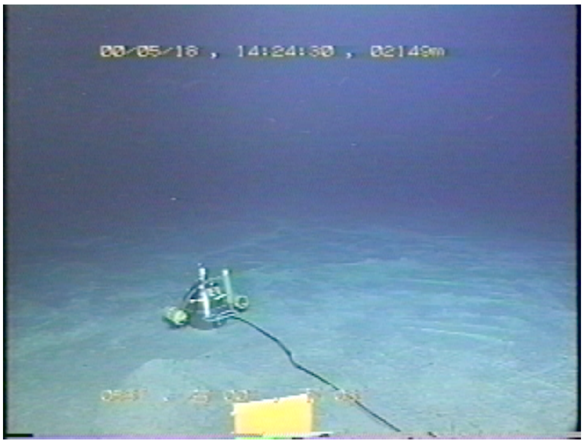

Fig. 4: Photograph of OBBS and cable connecting to JBX

The VENUS project was started in 1995 to develop a new concept for a submarine observatory. In this project, a geophysical MDOBO was developed using the decommissioned submarine cable GOGC. The system comprises MDOBO, OBTS, SMCC and land system. Digital data transmission using the coaxial analog cable is used. The OBTS and the seven instruments of the MDOBO were developed. In order to increase flexibility of installation and modification, the JBX with nine undersea mateable connectors was used, which enabled us to connect any instruments to a JBX in the deep sea. Several requirements arose due to the use of analog submarine cables, which were satisfied by mechanical and electronics designs. Using a cable ship, a deep-towing unit and an ROV, the OBTS and MSOBO were successfully installed at a depth of 2,157 m in the Ryukyu Trench during the period between August and September 1999. All data were successfully transmitted to JAMSTEC data center and stored in the mass-storage. The seven instrument of the MDOBO collected one and half month records.

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