Envisioned Network System for Future Underwater Observations

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ABSTRACT

Japan has developed 8 cabled observatories in the Japanese water in the past mainly to monitor earthquake activities and the installed observatories are all operating to aid earthquake studies for disaster mitigation at the future potential hazards. Recent technological challenges have introduced remarkable developments in the utilization of multi-disciplinary sensors in the deep ocean and now the installation of cabled observatories can include not only earthquake monitoring but various earthscientific objectives. This paper reviews the current cabled earthquake monitoring systems in Japan, the experiments for multidisciplinary observations, and presents clear objectives in the utilization of future cabled systems.

1. INTRODUCTION

Japan has started installing their cabled observatories for disaster mitigation purposes since late 70's. The Headquarters for Earthquake Research Promotion in the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has advocated to install at least five cabled observatory systems in 1996 for earthquake monitoring purposes. Now Japan Meteorological Agency (JMA), Earthquake Research Institute of the University of Tokyo (ERI), National Research Institute for Earth Science and Disaster Prevention (NIED) and Japan Marine Science and Technology Center (JAMSTEC) have respectively two, two, one and three systems operating mainly eastern to southern side of the islands. Objectives of these systems are, therefore, very clearly defined and they are dedicatedly used for monitoring earthquakes and hence disaster mitigation purposes. The advantages of utilizing cabled observatory systems were also reported as 1) improvements in earthquake detectability, 2) improvements in earthquake locationing, and, 3) enhancement of the knowledge on the nature of regularly generated earthquakes in the offshore[1]. The idea to deploy earthquake monitoring systems in the offshore has been proved efficient in the past for studying earthquakes taking place mainly in the offshore.

Recently, the development of multi-purpose marine observation sensors has opened the way to the utilization of multi-disciplinary observations and proved such systems could be developed to function on the sea floor[2] through a series of experiments using a decommissioned cable, junction box, sensors, and supporting facilities like deep-tow and ROV systems. It is, therefore, very important not only to monitor earthquakes as being planned but to include various monitoring capabilities which require long-term and real-time observations. The utilization of such technologies on multi-purpose sensors in cabled observatories would surely bring an ascent to the following scienfitic areas: (1) understanding of earthquake generation mechanisms, (2) unveiling deep Earth interior structure and hence its evolution, (3) drawing forth much deeper knowledge about ocean system and resolving solid earth-ocean-air interactions, (4) leading new biological findings, etc.

In this paper, we would like to introduce the present Japanese cabled observatory systems, then the latest state-of-the-art experiments or efforts on multi-disciplinary approach, and finally present directions for future observation systems. It is obvious that the preparation of infrastructure in the ocean is an indispensable method to take for future monitoring systems which are already technically realizable using versatile facilities in the world.

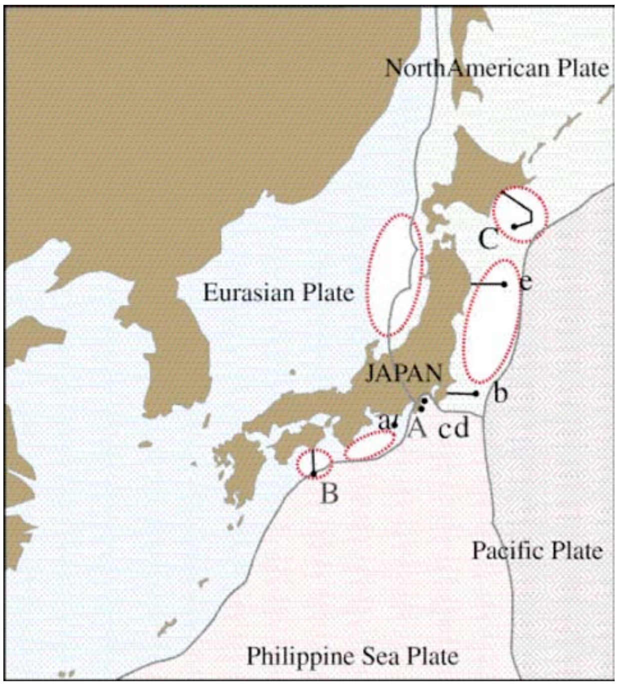


Fig. 1 Eight cabled observatory systems around Japan for Earthquake Monitoring and Engineering Developments. They are a) JMA Off-Suruga, b) JMA Off-Boso, c) ERI East Off-Izu Peninsula, d) NIED Sagami-Trough, e) ERI Off-Sanriku, A) JAMSTEC Hatsushima Engineering Development, B) JAMSTEC Off-Muroto, and C) JAMSTEC Off-Tokachi-Kushiro systems. Circled water areas were advocated by the Headquarters of Earthquake Research Promotion that the real-time observations are necessary for future potential of catastrophic earthquakes.

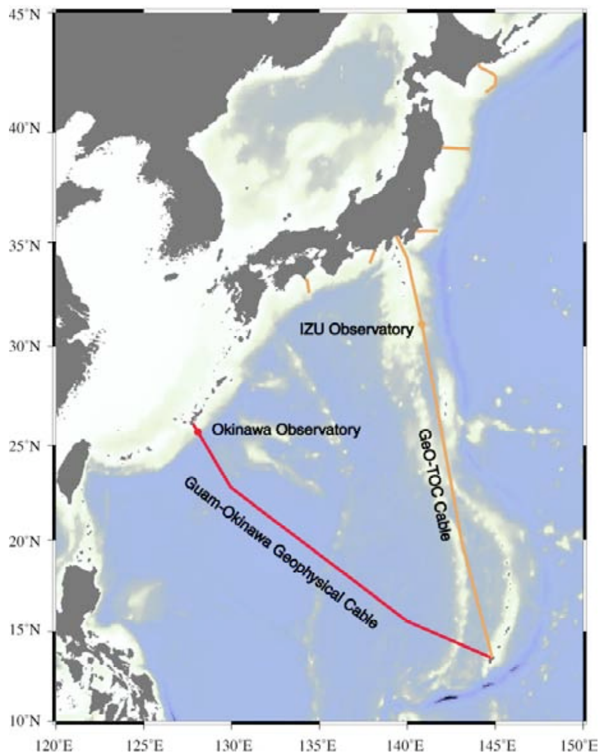
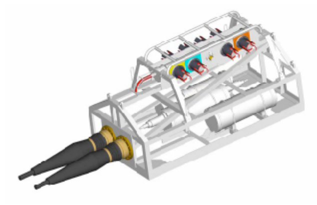


Fig. 2 Utilization of discommissioned cable in Japan. Two cables were utilized for scientific purposes. Two other sites in the GEO-TOC cable have been planned for future installation of a seismometer and geophysical observations[2]. Okinawa Observatory in the Guam-Okinawa Geophysical Cable represents the site for multidisciplinary observation experiment[3].



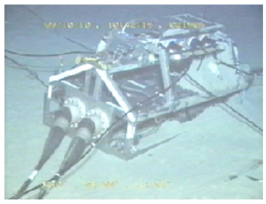


Fig.3 A junction box utilized in the VENUS experiment. (Left: Schematic drawing, Right: A real photo taken by ROV Kaiko)

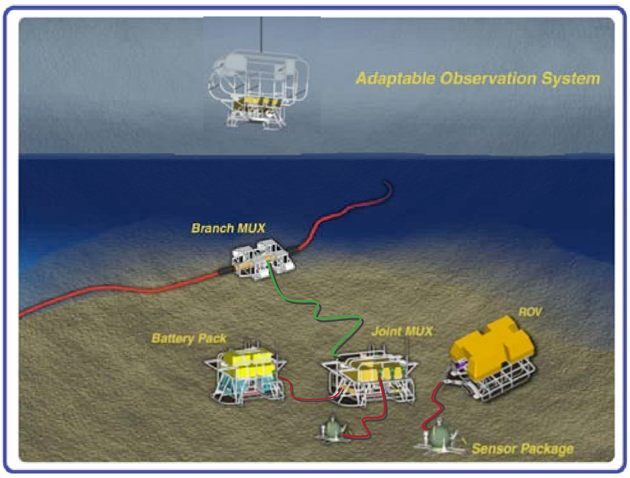


Fig.4 The main Off Kushiro-Tokachi cable system (thick red solid line with a branch-MUX) and adaptable observation system. The distance from the branch-MUX to Joint MUX was ca. 8 km and was shortened for observation purpose. The extension cable (green line) can be up to 10 km in the present design. An ROV Kaiko was used to mate the connectors on both side of the extension cable.

2. Japanese Cabled Observatories

2-1. Earthquake Monitoring Systems

Japanese islands are located at the intersection of four plates (Fig. 1). The collision of plates causes earthquakes at their boundary every several tens to a few hundred years. Figure 1 represents seven earthquake monitoring and one engineering developing sites of the cabled observatories in the Japanese water. They were installed in the last 25 years and the data are telemetered to monitor earthquake activity at plate boundaries. Three JAMSTEC systems have been equipped with marine environmental observation instruments and two of them have auxiliary ports available for future extension of the systems. One of discommissioned cable was used by ERI for earthquake monitoring after accommodating a seismometer inside a telecommunication relay[2] (IZU Observatory in Fig. 2).

2-2.Experiments for Multidsciplinary Observation

In 1997, an experiment has started utilizing a discommissioned cable and a junction box (Fig. 3) with auxiliary ports[3]. They have succeeded to connect plural sensors and their multidisciplinary observation lasted until the system has become dead due to corrosion. The utilized sensors includes a broadband seismometer, geodetic sensor, AUV tracer, geoelectromagnetic sensor, and hydrophone array, etc. Underwater mateable connectors were used for in-water mating/demating and acquired data were transmitted through the cable to land. Through the course of study, they have realized a multidisciplinary system on the ocean floor. It has become well known that the multidisciplinary observations are no longer a dream and that an ocean bottom cable can provide a versatile platform for any observation that requires real-time telemetry.

2-3.Extension of Cable using a Deep-Tow System and Adaptable Observation System.

One of the JAMSTEC cabled observatories has expandable ports for adaptable observation systems[4]. The ports utilize underwater mateable fiber optic connectors. In 2001, we have succeeded to extend a thin-wired fiber optic cable for ca. 8 km from the main cable system to install a broadband seismometer[5,6]. Figure 4 represents the schematic configuration of the main cable and adaptable observation systems. It is quite understandable that, in a technological point of view, the recent developments have already enabled the extension and maintenance of the underwater observation sensors or systems using deep-tow and ROV systems. Their system could use only fiber-optic communication and the branching of power was one of major hurdle in the system development.

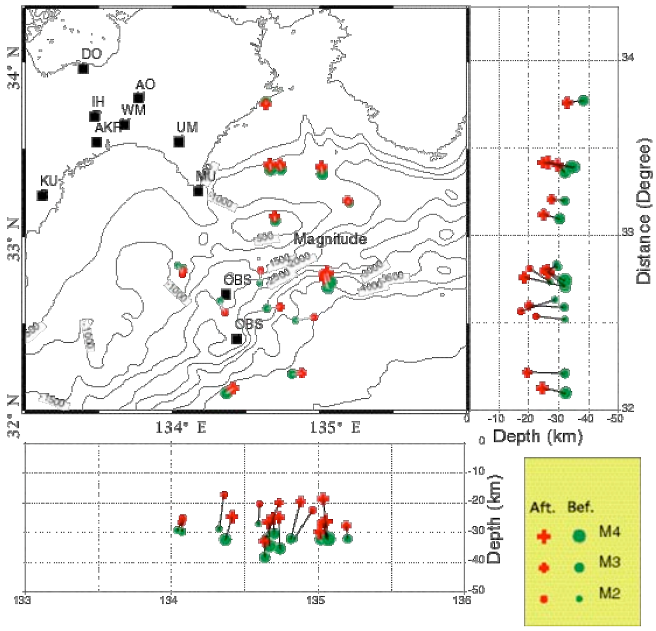


Fig. 5 Difference in the estimation of earthquake hypocenters. Vertical cross sections along NS and EW directions are respectively shown in right and bottom. Cross marks and solid circles are respectively after and before the inclusion of data from the cable observatory. It is shown that underwater seismometer constrain the estimated depth of the seismic events.

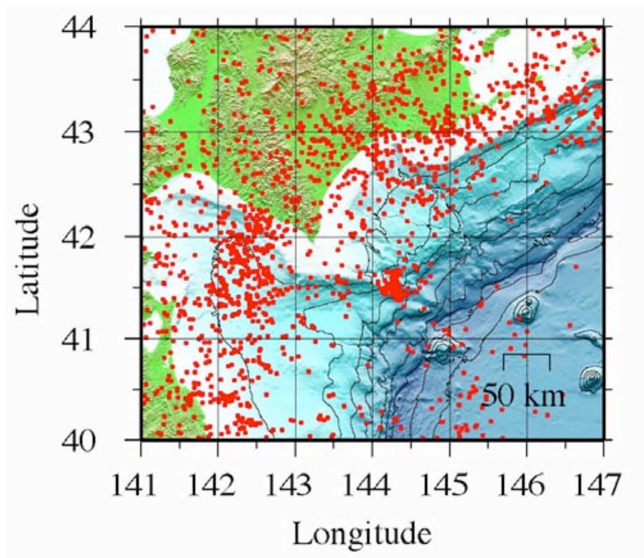


Fig. 6 Estimated hypocenter locations at off Kushiro-Tokachi by the JAMSTEC cabled system since August 1999 after the deployment of the system. The Pacific plate subduct beneath the island in northwestern direction with a rate of ~8 cm/yr. Many of the seismic events in southeastern offshore are not detectable from land observations. The installation of the cabled system has brought knowledg about the seismicity in the offshore and a link to structural surveys at this subduction zone.

3. Scientific Advances

3-1. Seismological findings

The installation of seismometers in the offshore has been well appreciated by seismologists for locating seismic events which takes place at the plate boundaries[7]. One of the JAMSTEC cable systems has shown that the earthquake hypocenters are located precisely after the inclusion of underwater observation data[1](Fig. 5). Figure 6 represents the location of microearthquakes which took place off Kushiro-Tokachi in a year after the installation of the cabled system. Many of the events were not detectable by land observations and, therefore, the system brought deeper knowledge about the tectonic environment around the area where the system was installed.

Pressure gauges attached to cabled observatories are working to detect tsunamis and underwater pressure fluctuations. The accommodation of tsunami data has enabled us to constrain the location of earthquakes in the offshore.

3-2. Environmental Observation on the sea floor

The JAMSTEC systems have environmental sensors such as acoustic Doppler current profilers, current meters, thermisters, hydrophones, etc. One of applications of such environmental sensors are (1) monitoring of deep water movements such as western boundary currents, (2) hygrogeological observation at cold seeps[8], (3) monitoring or detection of far field events[9] such as submarine eruptions, (4) solid earth-ocean interactions using pressure fluctuations, etc. Since cabled observatories have not been installed many, the spatial coverage of sensors in the deep ocean has been very limited and are awaited for improvements by deployment in near future.

3-3. Possible application of deep water observatories

The installation of deep water observatories has quite a huge possible targets. The recoverable resolution of seismic tomography for the interior of the Earth has been limited to ca. 2000 km for imaging beneath the oceans and is caused by sparse distribution of seismometers[10]. Earth scientists have tried to install as many seismometers as possible in the ocean[11] but yet suffers from poor coverage. Since the resolution of seismic tomography strongly depends on the average spacing of installed seismometers, both cabled and long-term seismic stations will surely enhance the resolution for the deep interior of the Earth and the image of much shallower part of the Earth. Seismic tomography has been recognized as one of the most interesting applications.

Geoelectromagnetic phenomena, especially ones originating from the deep interior of the Earth, are also one of the major applications of deep seafloor observatories. Electric potential differences connected by long cables have been used to detect deep origin of geomagnetic fluctuations[3]. These data would be used as a part of geoelectromagnetic tomography and must be analyzed with results from seismic tomography for obtaining the physical properties of materials in the deep interior of the Earth.

Solid Earth-air interactions have been reported to exist[13] and solid Earth-ocean or ocean-air interactions would be discussed in terms of material-exchange or environmental changes. Deep water is known to have a link with long-term climate changes but the details of the link have merely been revealed, yet. Observations to solve the above tomographic applications or inter-sphere interactions require dense and wide coverage on the ocean floor. Not surprisingly, the necessary conditions for these future observation surely supports the idea to realize multi-disciplinary observations.

Future Observations

- Geodetic/Seismic Obs.
- Thermal Obs.
- Oceanological Obs.

Using

1. Cabled Systems
2. Off-Line/Mobile Systems
3. Satellites
4. Bouys and AUV's

Targetting

- Earth Interior System
- Hazardous Events
- Solid-Ocean Interactions
- Air-Ocean Interactions
- Climate Changes

Fig. 7 Possible items for future observation systems in the deep ocean. Clearly defined objectives using multi-disciplinary sensors are identified not only for earthquake monitoring but for understanding the Earth systems.

4. Concluding Remarks

Scientists and Engineers have been trying to deliver instruments operating in the ocean and schemes to support those observation tools in the past. Through a long history of such efforts, now they have reached a stage to operate and to maintain both cabled and stand-alone observatories at depth in the ocean. Technologies we presented in this paper clearly indicates that they are ready to start designing the real future systems in the ocean. The experiments in the VENUS and adaptable observation system have shown that the technologies are ready at present for our dream, *i.e.,* future underwater network observations.

In the past studies, we have proved that the data obtained using cabled observatories were indispensable to understand the nature of earthquake occurrence. Since we are facing the next step in the understanding of earthquakes, observation systems reflecting the past experience have become of much importance in the design of such observations. Wide spatial coverage and increasing the number of sensors are the most essential requirements for earthquake studies and for understanding the other phenomena of the earth's system. For these observations, one of the best ways to take would be the deployment of observation infrastructure for the sea floor making it possible to install sensors in a denser way with wider coverage. Cabled systems with underwater mateable connectors, or moored buoy systems with power and efficient telemetry such as satellite ones are examples of possible infrastructures. The next step of our efforts is to make these platforms to be installed in the ocean for future observations. Figures 7 and 8 summarizes the items for such future network using currently available technologies.

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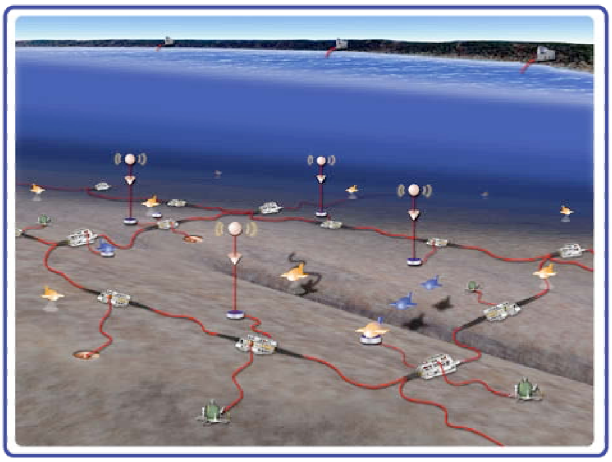

Fig. 8 Future underwater cabled observation system. Scientific observation will be conducted towards understanding of the Earth's interior, material exchange through the seafloor, interactions among atmosphere, ocean, and soild earth, etc. Plural landings will surely support keeping the network integrity. Marine facilities including AUV, ROV, moored observation system, etc., will be integratedly used to satisfy scientific requirements to observations and to maintain the system integrity.

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