International Workshop:

What can be done with seafloor observation networks?

March 10 and 11, 2008,
Tokyo Office of JAMSTEC,
Tokyo, Japan

University of Tokyo
Japan Agency for Marine-Earth Science and Technology

Co-sponsor: Japan Geoscience Union

International Workshop:
What can be done with seafloor observation networks?

Dates: March 10 and 11, 2008
Place: Tokyo Office of JAMSTEC

Host institutions: JAMSTEC and ERI, Univ. Tokyo
Co-sponsor: Japan Geoscience Union

Scope: Seafloor observation networks are now under construction in Japan, North America and Europe. In this workshop, researchers from the construction side and from user side meet together to discuss what can be done by the network data, how efficiently the data should be distributed among various communities, and what may be the future directions of seafloor networks. The workshop may end with mutual agreement on how to collaborate internationally.

Co-conveners

Barbara Romanowicz (UC Berkeley)
Hisashi Utada (Univ. Tokyo)
Yoshio Fukao (IFREE, JAMSTEC)
Yoshiyuki Kaneda (DONET, JAMSTEC)

Program

March 10 (Monday)

10:00 Yoshio Fukao (IFREE, JAMSTEC)
Introduction

10:10 Barbara Romanowicz (UC Berkeley) Keynote lecture from the user side
At the frontier between seismology and oceanography: scientific motivations for ocean floor observatories

10:50 Roland Person (IFREMER) Keynote lecture from the network side
ESONET: An European Sea Observatory Initiative

11:30 Jean Paul Montagner (IPGP, France)
How to improve global and regional tomographic models?

12:00 Mairi M.R. Best (University of Victoria, Canada)
Lessons Learned by NEPTUNE Canada in Installing the World's First Regional Cabled Ocean Observatory, North-East Pacific

12:30 Lunch

13:30 Dave Chadwell (Scripps)
Seafloor Geodesy in Ocean Observatories

14:00 Masataka Ando (Academia Sinica, Taiwan)
The seafloor geodesy in eastern and southwestern Taiwan and the MACHO project

14:30 Break

14:45 Sharon Kedar (JPL)
The origin of deep ocean microseisms in the North Atlantic Ocean

15:15 Kiwamu Nishida (Univ. Tokyo)
Background Love waves from 0.01 to 0.1 Hz

15:45 Katsuhiko Shiomi (NIED)
NIED Hi-net: High Sensitivity Seismograph Network in Japan

16:15 Break

16:30 Hisayoshi Shimizu (Univ. Tokyo)
Submarine cable geoelectric voltages to probe the dynamics of the Earth's core and mantle

17:00 Pascal Tarits (Brest)
Seafloor Geo-ELECTROmagnetic NETWORKS

18:00 Reception

March 11 (Tuesday)

9:00 Yasumasa Miyazawa, (FRCGC, JAMSTEC)
Operational Kuroshio forecast and ocean floor observation systems around the Nankai trough

9:30 Bruce Howe (University of Washington)
Acoustic Thermometry of Ocean Climate (ATOC): Results from the last decade and future possibilities using retired submarine cables

10:00 Katsurou Katsumata (IORGC, JAMSTEC)
Applications of seafloor pressure measurements

10:30 Break

10:45 Douglas A. Wiens (Washington University)
Constraints on the thermal structure and dynamics of island arc-backarc systems from ocean bottom seismograph deployments

11:15 Yasuyuki Yamada (JMA)
JMA's new Ocean Bottom Seismographs (OBS) using marine cable installed at the Sea of Enshu to the Sea of Kumano

11:45 Yoshiyuki Kaneda (DONET, JAMSTEC)
Dense Ocean floor Network system for Earthquakes and Tsunamis

12:15 Lunch

13:30 Discussion:
Chairman:
Hitoshi Mikada (Kyoto Univ.)
Commentators:
A. Schultz (NSF)
Masanao Shinohara (Univ. Tokyo)
Mariko Sato (JHOD)
Junzo Kasahara (JCSS)
Hiromi Fujimoto (Tohoku Univ.)
Frank Webb (JPL)
Seiji Tsuboi (JAMSTEC)
Kazumasa Oguri (JAMSTEC)
Hisashi Utada (Univ. Tokyo)
Yoshio Fukao (JAMSTEC)

At the frontier between seismology and oceanography: scientific motivations for ocean floor observatories

Barbara Romanowicz
Berkeley Seismological Laboratory and Department of Earth and Planetary Science, Univ. of California, Berkeley, USA.

While significant and impressive efforts have led to the deployment of state-of-the-art, high quality broadband seismic stations on land, as part of the global international seismic network, or through national efforts at the regional scale, deployment of seismic observatories in the oceans has lagged behind because of technological and logistical difficulties and an order of magnitude higher costs. Yet, two thirds of the earth's surface are covered by oceans. Many fundamental problems concerning the structure and dynamics of the earth's deep interior in general, and oceanic plates in particular, cannot be fully resolved without appropriately uniform global coverage. Moreover, even on land, continent to ocean transitions are disproportionately better covered from the land side, limiting our understanding of the many tectonically active areas bordering oceans. Last but not least, exciting new areas of research have recently opened up with the possibility of analyzing large quantities of continuously recorded digital data, and the realization that the low frequency background noise of the earth originates, to a large extent, in the oceans. At the same time, interest in the study of microseisms has been renewed. Elucidating the physical mechanism at the origin of these phenomena requires combining seismic observations on land and on the seafloor, with observations of ocean waves, at regional and global scales. I will be illustrating these questions with examples from recent work, making the case, in particular for the deployment of multi-scale, multi-parameter observatories in the oceans.

ESONET: An European Sea Observatory Initiative

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ESONET is a Multidisciplinary European Network of Excellence (NoE) associating 50 partners (research centres, universities, industrials and SMEs) from 14 countries: France, Germany, Italy, UK, Spain, Portugal, Greece, Belgium, Ireland, the Netherlands, Norway, Sweden, Bulgaria and Turkey. More than 300 scientists and engineers will participate to its activities.

The goal of the ESONET NOE is the lasting integration of European research on deep sea multidisciplinary observatories, through the construction of a permanent structure able to provide a set of ESONET CORE SERVICES, related to ESONET REGIONAL LEGAL ENTITIES. All the observatories will be linked for their implementation scheme as well as for a scientific and technical improvement process.

Over the initial 4 years, the approach is to merge the programmes of members Organisations by managing marine research activities addressing the common scientific objectives and by networking activities specially designed for Excellence integration and spreading.

The NoE will work towards establishing sea floor infrastructure which will provide platforms for instrumentation deployed throughout the water column and the geosphere below. Those platforms will provide power for instruments and real-time two-way data communications.

Key locations around Europe have been identified from which specific ones are selected for relevant science programmes of potential hazards, geo hot spots and ecosystem processes.

Amongst other actions, it works by establishing sea floor infrastructure that will provide platforms for instrumentation deployed throughout the water column and the geosphere below. Those platforms will provide power for instruments and real-time two-way data communications. Firstly, some “demonstration missions” have been selected in November 2007 and are presented here.

Development of international cooperation with observatory projects in North America and Japan is also one of the objectives of ESONET. It will allow establishment of standard at different level: sensors interfaces, power supplies; maintenance procedures, data format…

Demonstration actions are bringing technology excellence at high level for different development phases, implementing the standardisation and interoperability of the different platforms from the consortium. By acquiring relevant time-series of multidisciplinary data, they will be an input for integrated studies, common workshops and a material support to implement a data management plan. These results will be used to demonstrate the need of permanent long term observatories.

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How to improve global and regional tomographic models?

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The lateral resolution of large-scale tomographic models is limited by the uneven distribution of broadband seismic stations at the surface of the Earth. Below oceans, the structure of the upper mantle is primarily provided by the massive inversion of surface wave data, and the structure of the lower mantle is retrieved from the inversion of body wave data. Though the transition zone (between 400km and 1000km depth) has a key importance for understanding the coupling and the transfer of matter between the upper and the lower mantles, it is poorly constrained by both kinds of data, and it is difficult to have a lateral resolution smaller than 1000km. It is even worse for the anisotropic and anelastic parameters. Consequently, the fine structure of slabs or mantle upwellings at large depth below oceans is still controversial. We will illustrate how the installation of ocean bottom observatories might enable to address these scientific issues. For example the installation of an ocean bottom observatory in the Indian ocean might participate to improve the global coverage of the Earth, giving access to unsampled areas in the deep mantle and to investigate geodynamic processes below the Indian Ocean.

Lessons Learned by NEPTUNE Canada in Installing the World's First Regional Cabled Ocean Observatory, North-East Pacific

Mairi M.R. Best
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In the Fall of 2007, NEPTUNE Canada began the installation of an $100 million ocean observatory across the Juan de Fuca Plate. This will be an innovative network of realtime sub-sea laboratories linked by over 800 km of electro-optic cables. Five nodes, providing 10kW power and 4Gb/sec data transmission, will host interactive scientific instruments below, on, and above the seafloor. Continuous real-time multidisciplinary integrated measurement series will be delivered to a Data Management and Archiving System (DMAS) and from there, through the Internet, to researchers, decision-makers and the public throughout the world. This facility will transform our understanding of biological, chemical, physical, and geological processes across an entire tectonic plate from the shelf to the deep sea. Significant challenges include: securing adequate funding; innovative design of the nodes, junction boxes and vertical profiler; route planning and system deployment over challenging topography; building in-house a Data Management and Archive System with an observatory control system; periodic reduction in scope and aspirations; and developing collaborative relationships, including those with the Canadian and US navies, the commercial fisheries, and the First Nations. Opportunities abound for: extending and expanding the network and instrument arrays; international partnerships; commercial innovation and demonstration; educational and outreach programming; and nurturing new applications.

Seafloor Geodesy in Ocean Observatories

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Ocean observatories provide continuous, long-term access to the seafloor which is in constant motion driven by a number of geophysical processes. This consists of gradual movement associated with tectonic plate processes that can be imperceptible locally and abrupt movement along seafloor faults or slides that can have severe local impacts. The processes are of scientific interest and can have societal relevance. Seafloor geodesy provides a means to measure the seafloor motions. The time-of-flight of an acoustic signal and the speed of sound along the path combine to determine an underwater geometric range. Ranges can span local faults or be referenced to a global frame by tying one end to the Global Positioning System at the sea surface. Measurements repeated over months-to-years document the horizontal motion. Rapid vertical motions can be detected by measuring seawater pressure correcting for oceanographic signals. The constant access to power and telemetry that observatories provide is a natural fit with long-term seafloor geodetic monitoring. We examine how existing approaches can evolve into the observatory setting with particular application to subduction zones. Where combined with onshore GPS arrays it will be possible to measure deformation from incoming oceanic plate across the entire active zone to continental plate interior with temporal resolutions sufficient to capture a broad spectrum of natural processes.

The seafloor geodesy in eastern and southwestern Taiwan and the MACHO project

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Taiwan is located at a complex boundary between two subductions with opposite polarities. This collisional region has a convergence rate of at least 80mm/yr. The Ryukyu and Manila trenches located east and southwest of Taiwan, respectively, are believed to be poorly coupled aseismic subduction without significant large earthquakes (M>8.0). This perception is deduced mainly on the known historical earthquakes and tsunamis. However, the lack of other evidence can be due to the incompleteness of written history in relation with the lengthy subduction evolution. Considering these ambiguities, an observation technique is hereby proposed to elucidate regional plate boundary coupling conditions.

The method comprises of ocean-bottom crustal deformation system using KGPS and acoustic ranging techniques with an accuracy of 3 - 5cm +-1cm. In January and February this year, an observation offshore of Okinawa Island was initiated as collaboration between IES, Academia Sinica (Taiwan), Univ. Ryukyus and Nagoya Univ. (Japan) using this technique. Furthermore, another observation is now planned for a region off the northeast coast of Taiwan. The latter observation will be linked with the Marine Cable Hosted Observatory (MACHO) project.

The MACHO project is a submarine cable observatory offshore of eastern Taiwan. Its main purpose is to launch a marine observatory, to establish offshore seismic stations, to provide early warning of earthquakes and tsunamis, and to monitor submarine volcanic activity. This year the MACHO project is in its initial year wherein a route survey is being undertaken. The cable length for the first phase is planned to be 90km and could extend up to 500km long during its operation. In 2008, a local meeting is planned to discuss all the instruments that can be installed by the MACHO, like the marine geodesy as proposed in this paper.

The origin of deep ocean microseisms in the North Atlantic Ocean

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Oceanic microseisms are small oscillations of the ground, in the frequency range of 0.05-0.3 Hz, associated with the occurrence of energetic ocean waves of half the corresponding frequency. In 1950, Longuet-Higgins suggested in a landmark theoretical paper that (i) microseisms originate from surface pressure oscillations caused by the interaction between oppositely travelling components with the same frequency in the ocean wave spectrum, (ii) these pressure oscillations generate seismic Stoneley waves on the ocean bottom, and (iii) when the ocean depth is comparable with the acoustic wavelength in water, compressibility must be considered. The efficiency of microseism generation thus depends on both the wave frequency and the depth of water. While the theory provided an estimate of the magnitude of the corresponding microseisms in a compressible ocean, its predictions of microseism amplitude heretofore have never been tested quantitatively. In this paper, we show a strong agreement between observed microseism and calculated amplitudes obtained by applying Longuet-Higgins' theory to hindcast ocean wave spectra from the North Atlantic Ocean. The calculated vertical displacements are compared with seismic data collected at stations in North America, Greenland, Iceland and Europe. This modelling identifies a particularly energetic source area stretching from the Labrador Sea to south of Iceland, where wind patterns are especially conducive to generating oppositely travelling waves of same period, and the ocean depth is favourable for efficient microseism generation through the 'organ pipe' resonance of the compression waves, as predicted by the theory. This correspondence between observations and the model predictions demonstrates that deep ocean nonlinear wave-wave interactions are sufficiently energetic to account for much of the observed seismic amplitudes in North America, Greenland and Iceland.

Background Love waves from 0.01 to 0.1 Hz

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From 2 to 20 mHz, Earth's background Rayleigh waves are confirmed firmly even on seismically quiet days. Their observed features show that they are excited by random atmospheric disturbance and/or oceanic disturbance. Regardless of either atmospheric or oceanic origin, the phenomenon has been so far interpreted as the Earth response to pressure disturbance acting vertically on the Earth's surface, which can little excite Love waves.To our surprise, however, we detected clear background Love waves from 0.01 to 0.1 Hz by an array analysis of Hi-net tiltmeters (6/2004-12/2004). The ratio of kinetic energy of Love to Rayleigh waves is about 1 through the entire frequency range and through the whole time period. The predominant incident azimuths are common to both Rayleigh and Love waves, the strongest along the trench-arc systems and next from deep seafloor regions, the weakest from continental regions. These observations indicate that background Rayleigh and Love waves in the low frequency range below 0.03Hz are largely generated by the same mechanisms other than vertical pressure disturbance and that the most likely excitation source is shear traction acting effectively on the sea-bottom horizon that arises by linear coupling of infragravity waves with seafloor topography. This mechanism may not be applicable to the higher frequency range including the single frequency of microseisms, where infragravity waves are too strongly attenuated to couple with deep seafloor topography.

NIED Hi-net: High Sensitivity Seismograph Network in Japan

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After the 1995 Hyogoken-Nanbu (Kobe) earthquake, National Research Institute for Earth Science and Disaster Prevention (NIED) have constructed new high sensitivity seismograph network in order to determine hypocenter location precisely. We call this network "NIED Hi-net". The Hi-net stations uniformly cover the Japan Islands in addition to old high sensitivity seismographs operated by JMA, national universities, NIED, etc. Now, we have about 800 Hi-net stations.

Artificial noise from vehicles and factories are obstacles for detecting small earthquakes and determining their hypocenter locations precisely. To reduce these noises at the ground surface, we drill boreholes (> 100 m) and install high sensitivity seismographs at the bottom of them. In order to avoid large noises in urban area and/or area with thick sediment, we constructed the observation boreholes deeper than 1000 m. Recorded signals are continuously transmitted to NIED DMC using IP-VPN technology. The data also sent to the JMA and universities to be used for seismic activity monitoring and seismological research. Data from seismic networks operated by JMA, universities and other institutes are sent to NIED and NIED archives these data with the Hi-net data. These waveform data and JMA hypocenter catalog are available on the Hi-net website.

Submarine cable geoelectric voltages to probe the dynamics of the Earth's core and mantle

Hisayoshi Shimizu and Hisashi Utada
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Electric voltage measurements in the western Pacific using 1,000km scale submarine cables retired from telecommunications have been performed since 1992. The observed electric voltages have potential to reveal the dynamics of the Earth's core, mantle, and ocean. It is known that the toroidal magnetic field, which is hidden to the magnetic field observation on the Earth's surface, must exist in the core to sustain a self-exciting dynamo and is important to understand the dynamics of the core. The signature of the toroidal field can be detected through electric field if long cables are used for observation. The electrical conductivity structure of the mantle can be estimated analyzing the cable voltages together with geomagnetic field variations, and the obtained structure can be compared with structure of other quantities such as the seismic velocity to infer the dynamics and status of the mantle. Ocean currents of various time-scales such as tidal flow and global circulation have large effect on the cable voltages by motional induction in the ocean. In this talk, we will present some results on the toroidal magnetic field and the structure of the mantle. Also, we will comment on the importance of network for these studies.

Seafloor Geo-ELECTROmagnetic NETWORKS

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Measuring the earth electromagnetic field is concerned with answering fundamental questions about the Earth's deep interior and its near-space environment. The geoelectromagnetic data are of great use in several geophysical studies, such as core dynamics, decade-period changes in the length-of-day, the thermal core-mantle interactions or mantle electrical conductivity.

For the new and exciting satellite missions (OERSTED, CHAMP and soon SWARM) which investigate hitherto hidden features of the Earth's magnetic field, the role of ground observatories is essential to enhance the signal-to-noise ratio and to extract the various sources of the field, enabling a unique separation of the internal and external parts. The accurate determination of the main geomagnetic field and its secular variation at the global scale remains limited by the number of observatories and their poor distribution over the Earth's surface, particularly over the ocean areas. This biases significantly the determination of the source field geometry even at very long wavelength. The upcoming sea bottom geophysical cabled networks offer a unique opportunity to deploy clusters of geoelectromagnetic stations that will monitor and describe short wavelengths core and mantle features beneath the oceanic domains while participating to the densification of the global network of geomagnetic observatories for the next decade(s).

Operational Kuroshio forecast and ocean floor observation systems around the Nankai trough

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The Kuroshio, one of the most energetic western boundary currents in the world oceans, flows along the Nankai Trough and exhibits the significant path variations there. The dense ocean floor observation network system planned by JAMSTEC will provide useful information about the Kuroshio variation. For example, the water pressure obtained from the pressure gage array includes various kinds of ocean current variations such as tidal flow and the other phenomena. It is interesting to investigate feasibility of data assimilation or validation using such kind of data for the operational ocean forecast system predicting the Kuroshio path variation around the Nankai Trough. This presentation introduces the operational Kuroshio forecast system developed by JAMSTEC and discusses possibility of the utilization of the observation provided by the dense ocean floor observation system.

Acoustic Thermometry of Ocean Climate (ATOC): Results from the last decade and future possibilities using retired submarine cables

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Large-scale, depth-averaged temperatures have been measured by long-range acoustic transmissions in the North Pacific Ocean for the past decade as part of the Acoustic Thermometry of Ocean Climate (ATOC) project and the North Pacific Acoustic Laboratory (NPAL) project. Measured travel times along acoustic paths are compared with those estimated from three independent re-analysis products. There are similarities and differences in the ~1 s peak-to-peak variability. There are no discernable trends in the acoustic data or the re-analysis results. The basic acoustic arrival patterns agree with those obtained using the World Ocean Atlas (WOA) state; the mean states of two of the model-based products, however, differ so much from the WOA and the measurements that the re-analysis mean states must be replaced with the World Ocean Atlas state in order to obtain even first order agreement in acoustic travel times. The handful of paths that were realized in ATOC provided insufficient spatial coverage and sampling for climate purposes. Using trans-Pacific retired submarine telecommunication cables provides one possible way to support additional sources and receivers and thereby improve the spatial coverage. The same technology can clearly be applied in all the ocean basins and support other geophysical measurements.

Applications of seafloor pressure measurements

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On the seafloor, observable quantities relevant to physical oceanography include electric voltage along a cable, acoustic travel time, and pressure of the sea water. They can be interpreted as the volume transport of the sea water across the cable, temperature variations in the ocean, and the water depth, respectively. Because most of oceanic currents are in geostrophic balance, bottom pressure data are essential for accurate estimates of ocean transports, as demonstrated by a recent success of a program in the North Atlantic. Another variability potentially detectable by bottom pressure data is internal tides. Satellite altimetry has been successful in detecting surface signatures of the internal tides, and different spatial and temporal coverage of the seafloor pressure measurements provides an opportunity to reveal different aspects of the internal tides.

Constraints on the thermal structure and dynamics of island arc-backarc systems from ocean bottom seismograph deployments

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Ocean bottom seismograph deployments in Tonga-Lau (1994) and in the Mariana arc (2003-2004) provide detailed information on the seismological structure of these arc-backarc systems. The Tonga-Lau experiment consisted of 30 ocean bottom seismographs and 12 land seismic stations deployed for 3 months, in collaboration with Scripps Institute of Oceanography. The Mariana experiment consisted of 50 ocean bottom seismographs and 20 land seismic stations deployed for 10 months, in collaboration with the University of Tokyo, JAMSTEC, and Lamont-Doherty. Seismic velocity and attenuation tomographic models show large regions of low velocity and high attenuation in the upper 100 km of the mantle wedge. The seismic data are linked to mantle temperatures using temperature and grain-size dependent relations from Faul and Jackson [2005]. The observed Vs and Q anomalies in the upper mantle at depths less than 100 km in the arc and backarc predict temperature anomalies that are unreasonably large, suggesting the presence of melt and/or fluids. Shear wave splitting measurements provide significant information about seismic anisotropy and the mantle flow pattern in subduction zones. Both the Tonga and Mariana regions show a complex pattern of shear wave splitting results, with along-strike fast directions near the volcanic arc, rotating to arc-perpendicular (and roughly convergence parallel) in the far backarc beyond the spreading center. This general pattern of anisotropy can be replicated by 2.5 –D geodynamic modeling with strong along-strike flow within a low viscosity region between the arc and backarc spreading center.

JMA's new Ocean Bottom Seismographs (OBS) using marine cable installed at the Sea of Enshu to the Sea of Kumano.

Yasuyuki Yamada
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Japan Meteorological Agency (JMA) routinely monitors seismic activity in and around Japan, and issues Earthquake Early Warning (EEW), tsunami warning as well as earthquake information of the hypocenter and magnitude when earthquakes occurs. EEW is new service which make possible to warn people before strong ground shaking reaches them.

JMA started a project to install new Ocean Bottom Seismographs (OBS) using marine cable at the Sea of Enshu to the Sea of Kumano for improving the monitoring ability. By the new system, followings are expected as its effects.

(1) Precise understanding of plate boundary around the region by the precise locations of small earthquakes.

(2) Prompt detection of large earthquake using seismographs just above the focal regions, which is important for the EEW.

(3) Prompt detection of Tsunamis and precise estimation of its height. Tsunami gauges are set up at the cables as well as seismographs, which enable us to detect generation of Tsunami before its arrival at coasts.

The system are consisted of 5 sets of seismographs (1 set is 3 component velocity meter and also 3 component accelerometer) and 3 sets of Tsunami gauges. The total length of marine cable is approximately 220 km, and the seismographs and Tsunami gauges are set up inside the cable (including the terminal). Digitized data are transmitted using optical fiber in the cable.

The OBS will be installed in July, 2008, and will start its observation in August, 2008.

Dense Ocean floor Network system for Earthquakes and Tsunamis

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Around the Nankai trough, mega thrust earthquake over M8 is occurring with a interval of 100-150 years. The results of earthquake recurrence cycle simulation and last two earthquakes around the Nankai trough shows that the first ruptures seems to be starting around the Tonankai earthquake rupture zone in each recurrence cycle. Therefore, the Tonankai seismogenic zone is very important to elucidate the occurrence system of mega thrust earthquakes around the Nankai trough. Since 2006, the real time monitoring project of the Tonankai seismogenic zone is starting to understand mega thrust occurrence system. In this real time monitoring project, we will deploy the dense ocean floor network system with multi sensors such as seismometers and precise pressure gauges. This project has three important objectives as follows,

1) Speedy evaluation and notification for earthquakes and tsunamis.
2) Improve the recurrence cycle simulation of mega thrust earthquakes
3) Develop the advanced ocean floor observatory technology

We will introduce this project and future plan with the integration of international network projects.