The Ocean Hemisphere Network Project (OHP)

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Abstract. The Ocean Hemisphere Network Project (OHP) is a five-year long multidisciplinary project funded by the Ministry of Education, Science, Sports and Culture Japan. The project started in April 1996 in a schedule to end in March 2001, but its one-year extension has now been approved. The OHP aims to study and to build a new paradigm on the structure and dynamics of the Earth's deep interior by constructing a global network of multidisciplinary geophysical observations on the hemisphere including the whole Pacific where 90by ocean. The OHP network consists of three components, i.e., Seismic, Electromagnetic and Geodetic networks. Each network is further composed of observations of different technologies and/or methods. This article highlights topics of networking efforts of each component as well as status of data distribution and preliminary report of observational results.

1 Seismic Network

Japanese seismologists began to construct a seismic network at the Northwestern Pacific region in late 1980's, and named it as POSEIDON (Pacific Orient SEIsmic Digital Observation Network). The POSEIDON was not an organized network but cooperative observations by seismologists who managed oversea stations. The main purpose of the project was to exchange the seismic data and the know-how on the seismic observations in foreign countries. The instruments used there were not uniform, because maintenance of each station was left to the individual participant. It caused difficulties in systematic operation of the network and systematic management of the data in spite of great effort by the POSEIDON participants.

In 1996, the OHP took over the POSEIDON seismic network, and began to unify the observation system and improve the network. We designed the standard recording system with its total response equivalent to that of the IRIS network, and introduced it to every station. The seismometers were also changed to three components of STS-1 (360sec type) at stations where STS-2 was used. The seismometer vaults were also reconstructed, if necessary. Eleven stations in Japan, Russia, Korea, Philippine, Micronesia, Palau, Vietnam and Indone-

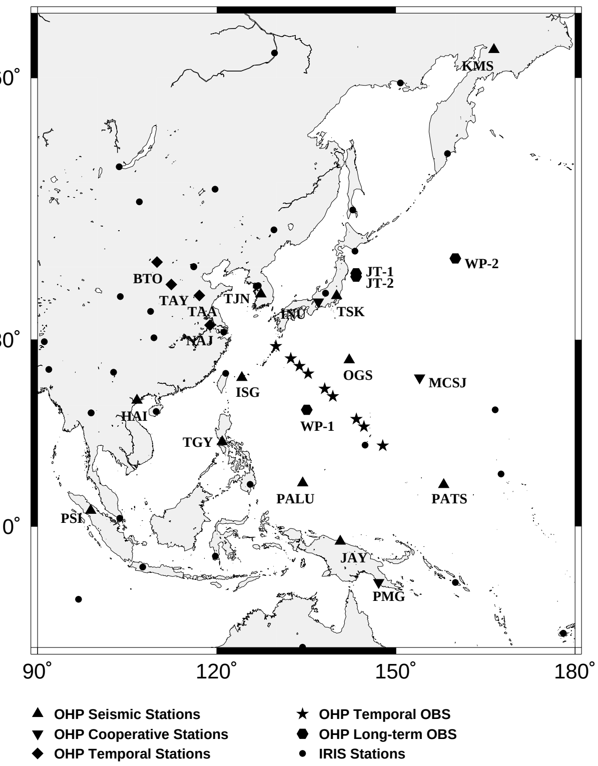

Fig. 1. Location map of stations of the OHP seismic network and IRIS one in the Northwestern Pacific region.

sia (solid triangles in Fig. 1) are now in operation, in addition to five cooperative stations (reverse triangles) with the IRIS, PRI (Polar Research Institute, Japan) and MRI (Meteorological Research Institute, Japan).

The seismic waveform data are sent to the OHP data center by mail once a month to compile there. The recording system has facilities for instrumental control and data transmission through telephone line and/or computer network, but we rarely retrieve the data by telephone line, because most of our stations are located at under-developed area, where the quality of telephone line is not good enough for data transmission. The situation about computer networking is even worse. The waveform data are only available at many stations, therefore, two or three months after they were recorded.

Besides the fixed OHP seismic network, we developed a portable observation system like PASCAL, which is composed of a set of broadband seismometer (CMG-3T: 100sec type) and portable recording system. The portable recording system developed here has remarkable advantages in high portability, easy handling, and low power consumption. Using this observation system, the temporal seismic observation has been carried out in China since Nov. 1999 under the collaboration with the China Seismological Bureau (Diamonds in Fig. 1). We also deployed fifteen semi-broadband ocean bottom seismometers (OBS) in the Philippine Sea for a period of 9 months in 2000–2001 (stars in Fig. 1) along a great circle path from the Tonga seismic zone to the Inner Mongolia region in China. The main purpose of this temporal observation was to sharpen the seismic images of deeply subducting slabs and the overlying mantle beneath the Philippine Sea.

In conclusion, during these five years of the OHP project, we have improved and expanded the broadband seismic network in the Northwestern Pacific region, which is augmented by the temporal array observation system of broadband seismometers.

2 Borehole Geophysical Observatories

Tomographic studies using seismic waves have revolutionized our understanding of mantle structure and dynamics. A great limitation on existing tomographic images of the Earth's interior is the uneven distribution of seismic stations, especially the lack of stations in large expanses of ocean such as the Pacific. The Ocean Hemisphere Network Project (OHP) has selected the western Pacific area for installation of ocean-bottom sensors because it is ideal for addressing problems related to plate subduction. The installation of four seafloor borehole geophysical stations in three areas was planned by OHP (Fig. 2). At present, three borehole geophysical stations were established by Ocean Drilling Program (ODP) and one borehole seismic station is scheduled to be installed in April 2001 during ODP Leg 195.

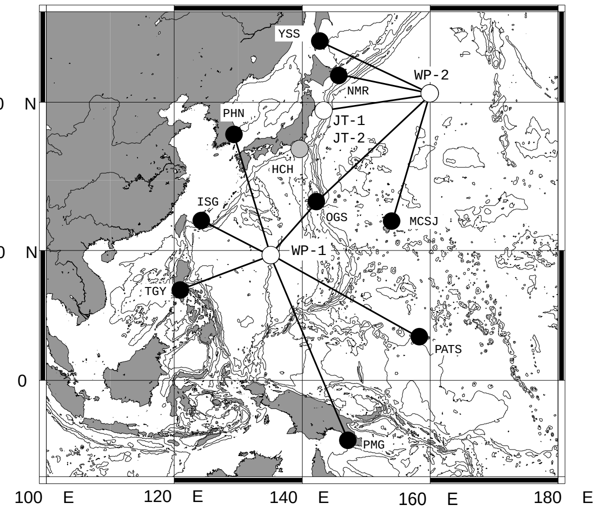

Fig. 2. Map of western Pacific area showing borehole geophysical sites. Solid circles indicate land seismic stations, whereas open circles are current and proposed seafloor borehole observatories. A few borehole stations effectively complement and expand the existing network.

Two stations (JT-1 and JT-2) are located immediately above the inter-plate earthquake generation zone on the landward side of the Japan Trench, and were installed in July 1999 to monitor ongoing tectonic processes in the deep sea terrace on the landward slope. JT-1 was located above the active portion of the seismogenic zone where large interplate thrust earthquakes recur and JT-2 is positioned above an aseismic portion of the seismogenic zone. JT-1 and JT-2 should improve greatly determinations of source locations and rupture processes of earthquakes near the Japan Trench. Two other sites (WP-1 and WP-2) are located to complete a 1000-km span network in the western Pacific area. The WP-2 station is situated on the normal oceanic Mesozoic crust in the northwestern Pacific Basin and was installed in August, 2000. WP-2 is of special scientific importance, since no other land site can replace this site. Accumulation of broadband seismic data from within the basin part of the Pacific Plate will help us to resolve structures of the lithosphere and asthenosphere of the Pacific Plate. The WP-1 site is in the west Philippine Basin, and is more than about 1000 km away from land stations. WP-1 will be a crucial network component in determining whether the Pacific plate is penetrating into the lower mantle in the Marianas Trench but not in the Izu-Ogasawara (Bonin) Trench.

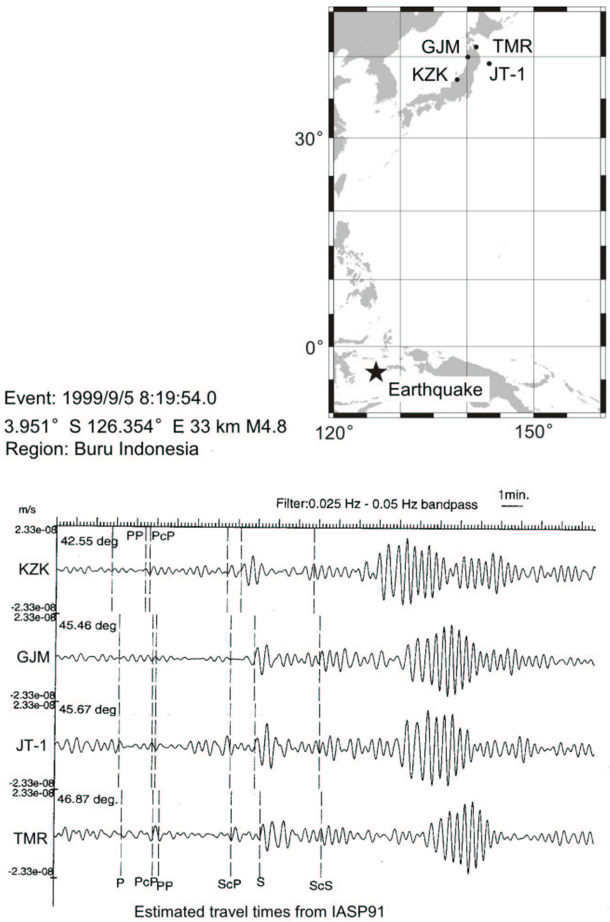

Fig. 3. Example of the data recorded by broadband seismometer at the JT-1 station. The data from nearby land stations are also shown. The component of each seismic trace is approximately radial to the hypocenter. The locations of the teleseismic event and the seismic station are also shown.

The observatories are designed to last for many years as a stand-alone system. For JT-1 and JT-2, the sensors consist of a strainmeter, a tiltmeter, and two kinds of broadband seismometers. The same broadband seismometers are used for the WP-1 and the WP-2. The sensors are housed in separate pressure vessels near the bottom of drill holes and are permanently cemented in as required for the strainmeter and tiltmeter operation and to assure good coupling for the seismometers. Separate cables connect the sensors uphole and the signals from the borehole sensors are sent to the seafloor. A data recorder and batteries to supply power to the whole system are installed on the seafloor. The data recorder is replaced using a Remotely Operated Vehicle (ROV) before the data storage becomes full. After installation, an ROV is needed to connect the seafloor unit to the borehole unit for activation of the system.

The ROV, Dolphin 3K, of the Japan Marine Science and Technology Center visited JT-1 and JT-2 and activated the systems in September 1999. Preliminary data covering an 8-hour interval were recovered from JT-1. Many seismic events were found in the record (Fig. 3). In October 2000, the ROV, Kaiko, visited WP-2 to activate the system. In a one-day visit of Kaiko, we recovered one hour of preliminary data from the borehole seismometers. It is confirmed from these preliminary records from JT-1 and WP-2 that seismic noise in seafloor borehole is low enough for highly sensitive, broadband observations.

3 Seismic Observation System on The Sea Floor

Under the OHP project, three types of long-term ocean-bottom seismometers (OBS) have been developed for seafloor observations over one year;
1) the very broadband OBS (LT-VBB OBS) covering periods of 360s~0.05s,
2) the broadband OBS (LT-BB OBS) covering periods of 30s~0.05s, and
3) the OBS (LT OBS) covering periods of 1s~0.05s.
Like our standard OBS using a short-period sensor of 4.5 Hz, the developed OBSs have been designed to be of free-fall and self pop-up type and to be deployed in the sea down to 6000 m in depth. "Long-term", "broadband", "compact", "portable", "reliable" and "robust" have been the key words in our developments of the OBS systems for the OHP project. The outlines of the three types of the OBS systems are as follows.

1) Long-Term Very Broadband Ocean Bottom Seismometer (360s~0.05s)

In order to cover the western Pacific with a denser seismic network, the OHP planned to have two quasi-permanent seafloor observatories in addition to the four borehole broadband seismic observatories by placing ocean bottom seismometers repetitively (Fig. 4). The LT-VBB OBSs were developed for these observatories (Fig. 5), which successfully continued to record seismic data over 400 days on the sea floor. The modified version of the Guralp CMG-1T is used as the three-component broadband velocity sensor of the LT-VBB OBS. The power consumption of the CMG-1T is lowered to achieve long-term observation. Through the RS232C serial interface to the CMG-1T, the OBS digital recorder (HDDR) controls intelligently

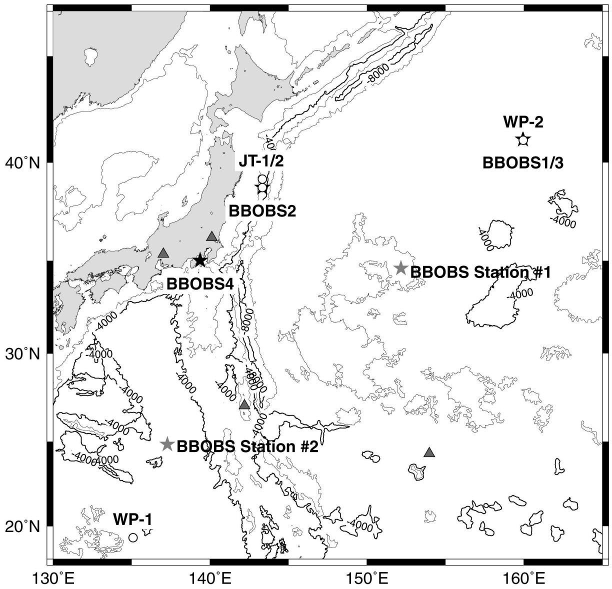

Fig. 4. The station map of the OHP observatories in the western Pacific. JT-1, JT-2, WP-1 and WP-2 are the borehole observatories. BBOBS stations #1 and #2 are the quasi-permanent observatories with using the long-term very broadband ocean-bottom seismometers (LT-VBB OBS) and have been planned to be installed in 2001. The experimental observations for developing the LT-VBB OBS were held four times at the sites of BBOBS1 to BBOBS4 between 1999 and 2000.

the on/off of the power of the sensor, the locking/unlocking of the pendulum, and the centering of the mass of the pendulum. The CMG-1T is mounted on the active-controlled leveling system that we developed specifically for the LT-VBB OBS (Fig. 6). Each velocity component of the CMG-1T is digitized by the 20-bits analog-to-digital converter of the HDDR at a sampling rate of 128 Hz. The sampled data are recorded continuously with a time tag on the four 2.5-inch hard disks using memory buffering of 5M bytes. The HDDR recorder, the CMG-1T sensor mounted on the leveling system, the electronic circuit boards of the acoustic transponder, and Lithium batteries are contained in a 65 cm diameter sphere made of titanium alloy. The acoustic transponder has a function of data transmission that enables us to check the health of the LT-VBB OBS on the seafloor remotely from a surface ship and to change the observation parameters of the LT-VBB OBS. Such communications between the seafloor instruments and the surface ship is essential for the long-term observations on the seafloor in order to make the observations being flexible and reliable. Forced electric corrosion is utilized for releasing the anchors being attached outside the titanium sphere of the LT-VBB OBS. Once a command is sent to the LT-VBB OBS acoustically from a surface ship,

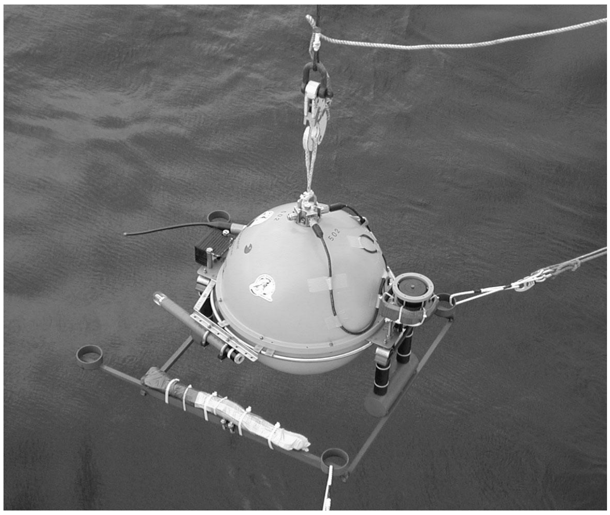

Fig. 5. The exterior view of the long-term very broadband ocean-bottom seismometer (LT-VBB OBS).

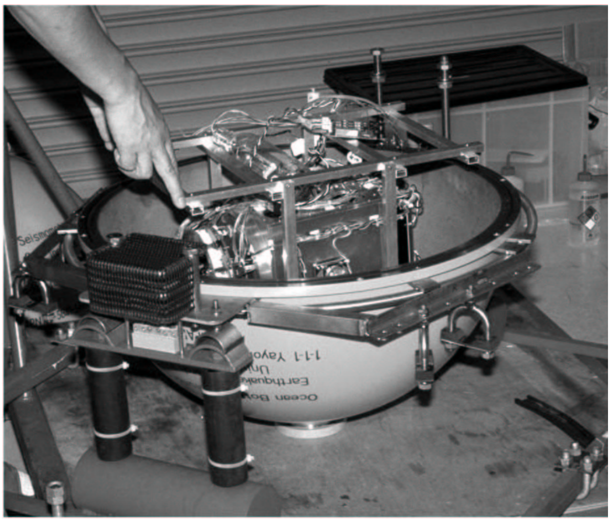

Fig. 6. The view of the active-controlled leveling system for the CMG-1T sensor installed on the titanium hemisphere.

it activates the forced electric corrosion to dissolve the titanium plates of 0.5 mm thickness to release the anchors. The LT-VBB OBS then begins to ascend to the sea surface to be retrieved by the surface ship. All the LT-VBB OBSs were successfully retrieved after more than one-year observations on the seafloor, demonstrating a high reliability of our system.

2) Long-term Broadband Ocean Bottom Seismometer (30s$\sim$0.05s)

We developed a long-term broadband OBS (LT-BB OBS) using the PMD sensor covering periods of 30s$\sim$0.05s. The HDDR recorder, the PMD sensor, the acoustic transponder and Lithium batteries are contained in a 50-cm diameter sphere of titanium alloy. The period of continuous recording is about 540 days. The LT-BB OBS is compact and costs lower than the LT-VBB OBS. The 15 OBSs were deployed along a 2,500 km long profile in the Philippine Sea and succeeded in the one-year observations of teleseismic events during 1999–2000.

3) Long-term Ocean Bottom Seismometer (1s∼0.05s)

The Lennartz 1 Hz sensor is used for the long-term OBS (LT OBS). The sensor is mounted on the active-controlled leveling system, the mechanism of which is similar to that of the LT-VBB OBS. The observation period is about 500 days in a system with the HDDR recorder and the titanium sphere of 50 cm diameter as a pressure housing.

4 Geoelectromagnetic Network

The OHP geoelectromagnetic network (Fig. 7) aims to study electrical conductivity structure of the Earth's mantle, Earth's main field variations and core-mantle dynamics. It consists of long-term (nearly permanent) geomagnetic and geoelectric observatories, and supplementary mobile surveys. Eight geomagnetic sites have been installed in the Pacific region, where pre-existing permanent observatories are few. Locations are Pohnpei (FSM), Kiritimati (Kiribati), Huancayo (Peru), Changchun (China), Tongatapu (Tonga), Marcus (Japan), Muntinlupa (Philippines), and Majuro (Marshall Islands). These observatories are equipped with an identical magnetometer system, the OHP magnetometer (Shimizu and Utada, 1999). The OHP magnetometer is designed for a long-term observation with needs of little maintenance (monthly visit to change disk, and absolute measurement once a year). It consists of a proton magnetometer to measure the total intensity and a three-component fluxgate magnetometer (Shimizu and Utada, 2000). The three component sensor is highly sensitive (resolution 0.01 nT, noise level 0.05 nT) so that data can be used for induction studies by analyzing rapid geomagnetic variations or for ionospheric studies. It is also possible to control three-component absolute values with an accuracy of a few nT, only by conducting an absolute measurement every year. Therefore the OHP magnetic data can be used for study of secular variations.

Submarine coaxial cables retired from telecommunications services are utilized to get information on the Earth's deep interior. By analyzing rapid variations (10 minutes to 10 days of period), we try to determine the electrical conductivity distribution beneath the Pacific. For example, one-dimensional inversion of magnetotelluric (MT) response from the Hawaii-Midway cable indicated a sharp increase of conductivity at around 400 km depth. Another purpose of the cable voltage measurements is to detect an electric field variation related to the toroidal magnetic field at the surface of the outer core, which is possible to exist with a finite lower mantle conductivity. Such field variation is probably detectable but needs many decades of observation as already pointed out by Shimizu *et al.* (1997).

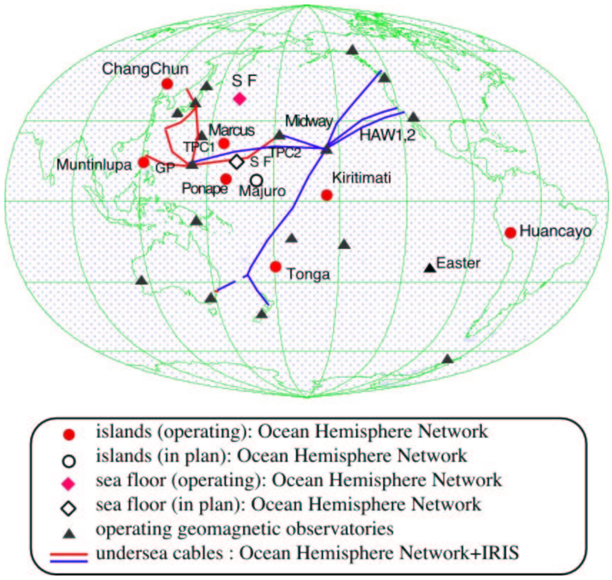

Fig. 7. Location map of stations of the OHP geoelectromagnetic network which consists of geomagnetic observations on land and on ocean bottom and electric field measurements by submarine cables.

Distribution of these permanent observatories is sometimes not dense enough for detailed studies, especially to study the mantle electrical conductivity structure in the subduction zone of the northwest Pacific. In order to increase the spatial resolution, we have carried out two kinds of temporary array observations: Ocean Bottom ElectroMagnetometer (OBEM) array in the Philippine Sea and Network-MT experiment in Northeast China.

In northeast district of China, there exists active Quaternary volcanism that is neither of hot spot origin nor of island arc type. Corresponding to the location of volcanoes in this region, global seismic tomography delineates a presence of high velocity anomaly at around the mantle transition zone, which is interpreted as a stagnant slab (*e.g.*, Fukao *et al.*, 1992). This situation is geologically interesting enough to conduct further studies on the mantle structure in details, for example, Network-MT (Uyeshima *et al.*, 2001) experiment. Electric field variations are measured by using telephone lines to connect electrodes. This enables us long (>10 km) electrode spacing that provides high S/N especially at lower frequencies. Since the summer of 1998, we have conducted electric field measurements on seven telephone lines in this region and obtained good data from four lines. These data were processed with the geomagnetic data at Changchun (OHP magnetometer) to obtain magnetotelluric responses from 100 seconds to several days. One-dimensional inversion of the responses indicated the presence of anomalous conductor in the upper mantle and deeper (600–800 km) conductivity jump than those found beneath the Pacific.

Fig. 8. Outerview of SFEMS3.

5 Seafloor Electromagnetic Station: The Third Generation

The third generation of SeaFloor ElectroMagnetic Station (SFEMS) has been delivered to us (Fig. 8). SFEMS was developed for:

1. Probing the electrical conductivity structure of the deep Earth via long-term seafloor magnetotellurics.
2. Estimation of the lower mantle conductivity by detection of geomagnetic secular variations.
3. Understanding dynamics in the Earth's core by improving the distribution of the existing geomagnetic observatories. In addition, a combination of the geomagnetic total force measured by SFEMS's absolute scalar magnetometer with the vertical magnetic component of a magnetotelluric (MT) variograph of SFEMS may provide us with the correct geomagnetic potential in regions where continuous EM observations have never been carried out (*e.g.*, the northwest Pacific).

The prototype SFEMS (the first generation) was equipped with an Overhauser absolute magnetic sensor and an acoustic telemetry modem (ATM) in addition to its basic platform made of titanium. It was used to confirm reliability of the absolute magnetometer and of the realtime data transmission by ATM in two experiments (1996-1997, KH96-3 by R/V Hakuho, ORI, U. Tokyo, cruises by #7 Kaiko and R/V Ten'yo of Maritime Safety Agency, Japan). An MT variograph was further implemented to the prototype to form the second generation of SFEMS, which was tested in KH98-1 around the East Mariana Basin to yield a 40-day long 8-component dataset successfully. In the third generation, a fibre optical gyro (FOG) was also attached to know instrument's geographical orientation. All the client sensors (the Overhauser magnetometer, the MT variograph and the FOG) can now be controlled from the sea surface by means of ATM.

The third generation of SFEMS was deployed in the northwest Pacific in the summer of 1999 (KH99-3). It was originally planned to be recovered by MR00-K03 in May-June, 2000 (R/V Mirai, JAMSTEC) but was unfortunately not retrieved since the acoustic release system failed to function well. Hence, it was towed to the surface by ROV Kaiko under the support of its tendership, R/V Kairei (JAMSTEC), at the end of October, 2000. The failure turned out to be due to current leakage from the acoustic releaser. The renewed SFEMS was tested in the Gulf of Aden, Indian Ocean during KH00-5, which successfully provided us with a 21-day long 8-component time series (Fig. 9) with an instrument's orientation of 189.50° from the geographical north. Although the SFEMS is still a pop-up type instrument using primary lithium cells for main power supply, it can be made to a semi-permanent seafloor observatory by periodical servicing using remotely operated vehicles (ROVs) which will replace the SFEMS's primary cells and the data recorder.

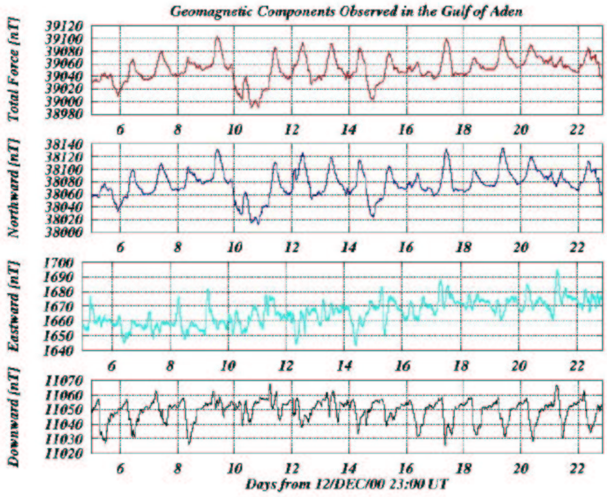

Fig. 9. Four-component magnetic data collected in the Gulf of Aden.

6 GPS Network and Result of Data Analysis

The Japanese research group of tectonics using the Global Positioning System (GPS) has constructed an array of permanent tracking stations in the western Pacific and the eastern Asia since around 1995. The project was promoted under the Ocean Hemisphere Project (OHP) as well as other research funds. Western Pacific to eastern Asia is the area of convergence among several mega-plates including Eurasia, Pacific, Indian-Australian and North American plates. A variety of geodynamic phenomena take place in this area such as continental collision in the Himalayan area and large scale intraplate deformation in Chinese continent, subduction of oceanic plates and back-arc spreading behind the subducting plates as well as instantaneous events such as earthquakes and volcanic eruptions. Although geological plate motion models have been proposed for these large plates such as NUVEL-1 (DeMets *et al.*, 1990) to investigate tectonics in this region, those large scale model lacks in including proposed smaller scale plates such as Amurian plate, Okhotsk plate, Caroline plates etc. It is thus primarily important to clarify instantaneous displacement rate field in this region to clarify tectonics and investigate geodynamics in the region.

Among various space geodetic techniques, the Global Positioning System (GPS) is the most appropriate technique considering accuracy and logistical expenses. We have established more than 10 permanent GPS stations since 1995. The network was named as Western Pacific Integrated Network of GPS (WING). In addition, more than 10 stations of International GPS Service for Geodynamics (IGS) have been established by other institutes in this region in the same time period. Also, the Geographical Survey Institute of Japan has established a dense national array called GEONET since around 1996 with about 1000 permanent stations in the Japanese islands; from which we used only seven sites that are open to IGS community.

In the present study, we used data at 38 stations in total from above GPS networks for baseline analysis for the period July 1995 ~ June 1998, together with 6 IGS global fiducial sites. We employed the Bernese software ver.4.0 and used the Melborne-Webbena linear combination for fixing initial phase ambiguities for long baselines. A fiducial-free approach was adopted to obtain the most accurate baseline estimates. To fix the estimated coordinates to the terrestrial reference frame, the Tsukuba IGS site was assumed to be moving about 2 cm/yr westward relative to the stable Eurasian continent (Heki, 1996). Fig. 1 shows the summary of the displacement field thus obtained. The figure includes not only results from the permanent array but also those from campaign observations conducted in the same region (Kato *et al.*, 1998). The figure portrays the displacement rate field in the western Pacific and eastern Asian region. We find that velocities of sites that are within the oceanic plate and far from boundaries are in good agreement with rigid plate motion models. On the other hand, Ishigaki and Guam seem to be moving trenchward relative to the Philippine Sea plate, suggesting on-going back-arc openings. Stations in the Asian continent such as Lhasa, Xian, Wuhan, and Shanghai are moving NE-E relative to the stable Eurasian continent, due possibly to the collision between India and Asia and the stress propagation toward east. Then, the Euler vector of the Philippine Sea plate relative to the Eurasian stable craton was estimated using thus obtained GPS data. For this purpose, we used repeated observation data at Okino Torishima (Parece Vera) and velocity vectors at some sites on the Philippine Sea plate in the nationwide continuous monitoring network by GSI. The estimated location of the Euler pole is (41.55°N±0.42°, 152.46°E±0.43°) and the angular velocity is -1.50°±0.04°/ma taking counterclockwise rotation as positive (Kotake *et al.*, 1998). n addition to establishing a permanent GPS array in the western Pacific region, we have conducted various campaign observations along the plate boundaries such as in the Mariana, Yap and Palau area (see Fig. 10) under international cooperative projects. We are also trying to synthesize these velocity fields under the unified kinematic reference frame based

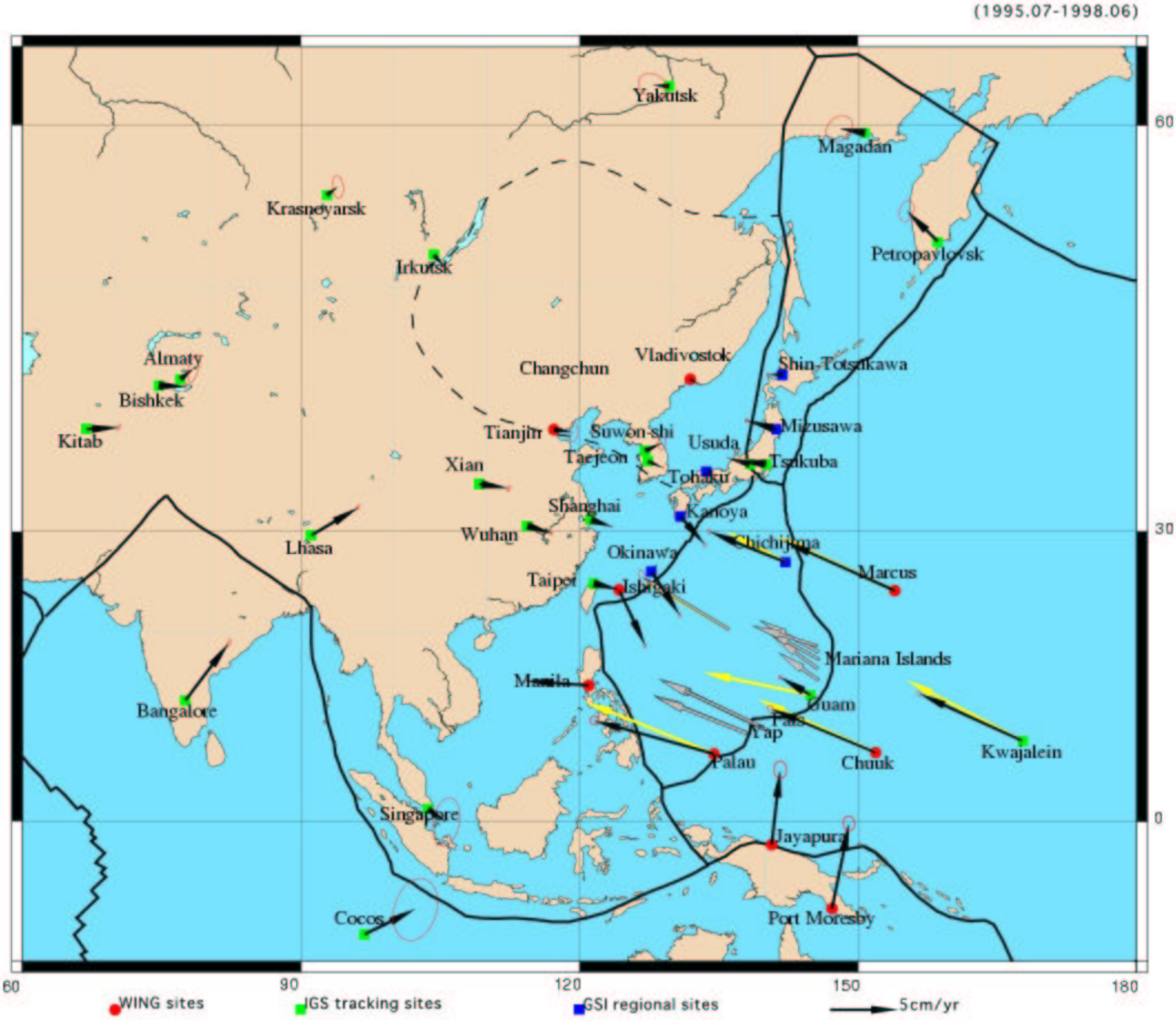

Fig. 10. Velocities at the GPS sites in the western Pacific area. Black arrows: estimated velocity by GPS, Yellow: estimated velocity by plate motion models.

on published data. The obtained velocity fields will provide us with fundamental information to help understand complicated tectonic process in the region. Given this permanent array of GPS, we have to think further developments of study in the area. First, the array may have to be augmented to obtain more detailed picture of tectonic deformations in the area. Since the area is under fragmented tectonic blocks and widely spread deforming area in China, many more sites are clearly necessary to fully understand the tectonic motions in the area. Secondly, we have to consider that GPS is now used not only as a tool for solid earth physics but also as that for atmospheric sciences. The signal transmitted from the GPS satellites keeps information on atmosphere, namely, content of water vapor along the path. Estimated water vapor content over the site provides important data for meteorology and hydrology. Thus a number of projects of using GPS as an observation tool for atmospheric sciences in recent years. A part of our array in the western Pacific and Asia will be handed over to the Hydrological Cycle Observational Research Program under the Frontier Observational Research System for Global Change, which is aiming at the mechanism of Asian Monsoon. Considering these, GPS regional array established in this study should be combined with other regional arrays on the globe to be a global infrastructure of earth science.

7 OHP Superconducting Gravimeter Array

Under the support of the OHP, the Japanese superconducting gravimeter group is operating an international observation network with superconducting gravimeters (SG) called GGP-Japan Network. This network consists of the following seven observation sites; from the north, Ny-Alesund (Svalbard, Norway), Esashi, Matsushiro and Kyoto (Japan), Bandung (Indonesia), Canberra (Australia), and Syowa Station (Antarctica). An important characteristic of the GGP-Japan Network is its spatial distribution of the sites on the globe, that covers a wide range of latitude from 79° north (Ny-Alesund) to 69° south (Syowa) including a station near the equator (Bandung). This unique characteristic is important for the studies of latitude dependency on the Earth's free oscillations and the Earth tides.

Through changes in currents and ocean-bottom pressure, oceans have significant impacts on many global geophysical processes of the Earth such as the polar motion excitation, measurable change in the length of the day, changes in the Earth's gravitational field and the motion of center-of-mass of the solid Earth. Sato *et al.* (2001) discussed the effect of sea surface height variations on superconducting gravimeter measurements made at the three different sites of GGP-Japan Network, namely Esashi, Canberra and Syowa. Although there remain some systematic discrepancies in both amplitude and phase, good agreements with gravity measurements at all of these sites were obtained using the results from an ocean model (POCM by Stammer and Chervin, 1992) and from the TOPEX/POSEIDON measurement which had been corrected for the steric changes in sea surface height that have no gravitational signature (Figs. 11 and 12). Their results suggest that the GGP-Japan network may give a useful data set that can be used for the comparison and/or the combination with the data obtained from the satellite gravity missions as CHAMP, GRACE and GOCE.

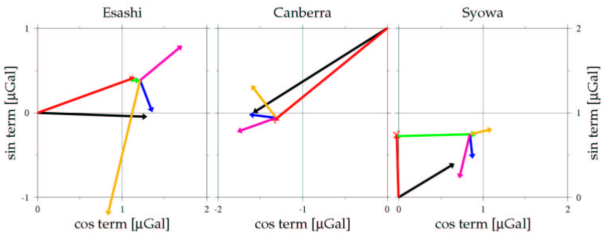

Fig. 11. Phasor plots of the observed annual components and predicted ones. The phase angle of each vector is referred to an analysis epoch of 00h UTC, January 1, 2000, and the angle is measured from the cosine axis, counter clockwise for a lag. The three vectors in black, red and green show the observation, the polar motion effect and the effect of solid tide, respectively. The effects of the Sa ocean wave are very small to display with the scale of this plot. The three vectors of yellow, blue and pink show the effect of SSH variations evaluated from the POCM data using the steric coefficients of 0.0×10^{-2}m/deg, 0.60×10^{-2}m/deg and 1.0×10^{-2}m/deg, respectively.

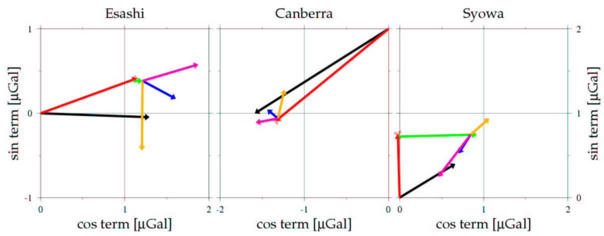

Fig. 12. Similar plots as Fig. 11, but the SSH vectors evaluated from the TOPEX/POSEIDON data are displayed.

8 Long-Term OBS Array Observation across The Philippine Sea

As a part of the Ocean Hemisphere network Project, a long term ocean bottom seismic observation was performed along the trans-Philippine Sea profile. The main aim of this experiment is to reveal an image of inhomogeneous mantle structure beneath the west Pacific region from analyses of body wave records of the events that occurred on the elongation of this profile, mainly around Tonga and Fiji Islands.

From Nov. 1999 until July 2000, we conducted the observation by using 15 long term ocean bottom seismometers (LTOBS) equipped with semi broad band sensors (WB2023LP, PMD) along the profile (Fig. 13). The profile is about 2800 km long and NW-SE trending across the Saipan Island. Its NW end (28°N, 130°E) is located near the Amami Ohshima Island and the SE end (10°N, 151°E) is located oceanward away from the Mariana Trough. Six ocean bottom electro-magnetometers were simultaneously deployed on the same profile to improve the image from an individual information of the deep structure. We also installed four land broadband seismic stations along the extension of this profile in China.

During the deployment, we performed a precise positioning of each LTOBS. We also conducted one-dimensional refraction with an airgun (1000 cu.in.) and single channel reflection surveys at many stations as possible to understand the crustal structure

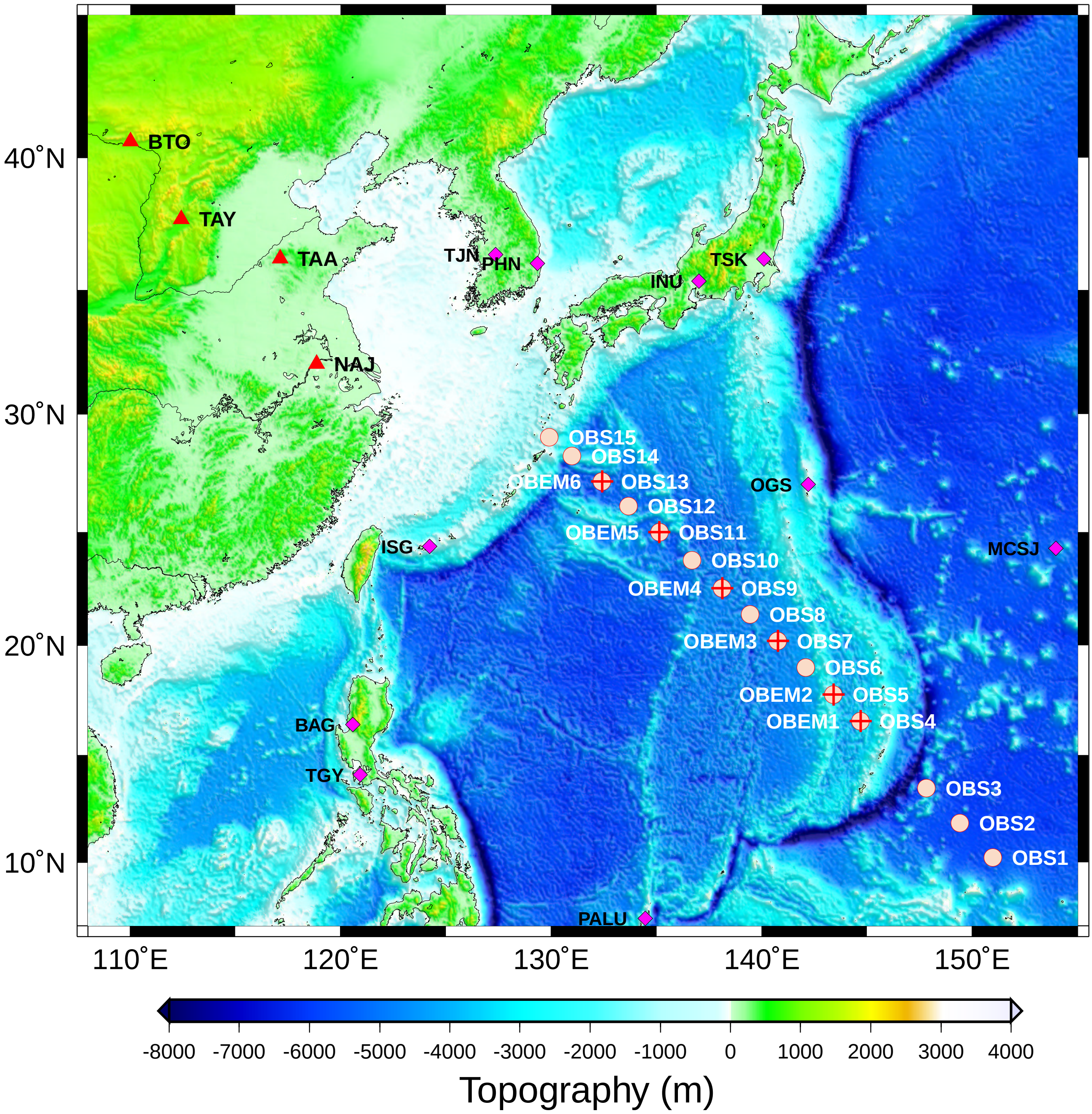

Fig. 13. Location map of OBS array and land stations. 15 LTOBSs and 6 OB EMs are indicated as circles and crosses, respectively.

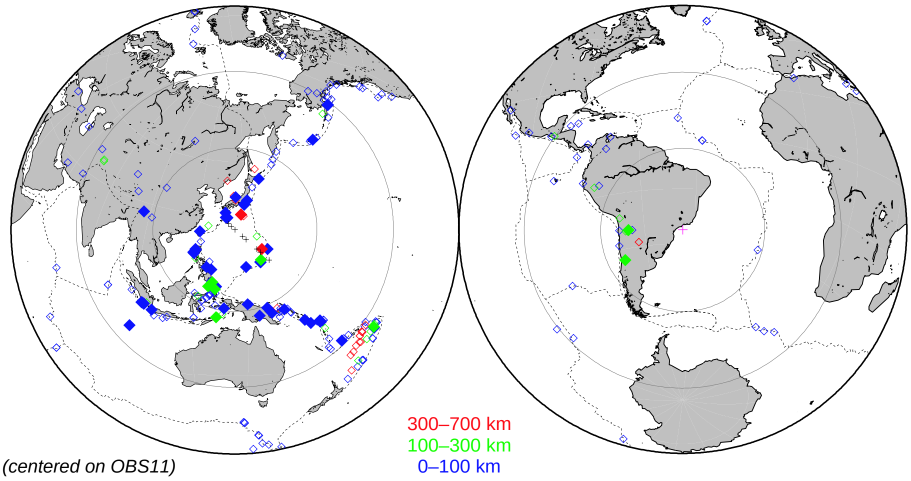

Fig. 14. Quality map of the LTOBS array data. Signal to noise (S/N) ratios are examined for records of events with Mb>5.5 (PDE), filtered in 10∼100 mHz band (Note: this may not be a suitable band to identify onset of direct *P*). Filled symbols are for "good" events, for which S/N ratios are high at more than three stations. Scale-over occurs for local events (<15°), especially for deep events.

beneath the OBS position. We finally recovered 13 OBSs, but 4 of them did not work due to malfunction of a sensor control unit. We retrieved the data from the other OBSs which were fortunately located almost evenly on three different basins, the West Philippine, Shikoku and Mariana Basins.

We will report the result of the detailed noise analyses elsewhere. The records show commonly a high noise level in 0.1∼1 Hz, that can be an obstacle for body wave analyses, especially in horizontal components. For this reason, the analyses for the moment are limited in a frequency band below 0.1 Hz. The data quality is preliminarily examined with the records band-passed in 30∼100 mHz band, using PDE catalog (Fig. 14). Events with Mb 5.5 or larger within epicentral distances of 70 degrees are well recorded with adequately high S/N. Some large events are well recorded in lower frequency bands, though the noise level is slightly high in horizontal components. Most of them are shallow events, but several deep events in Japan, Izu-Mariana and Fiji are recorded as well. Majority of the recorded regional events are located in the equatorial southern Pacific, from the Philippine to Fiji islands. Some events in Alaska are well recorded with high S/N. Dispersion of Rayleigh waves from these shallow events are characterized by the oceanic signature, and our new data set will provide a unique opportunity to investigate wave propagation and the upper mantle structure in oceanic regions.

An example record section of this array, land stations and a broad band OBS (BBOBS) in the northwestern Pacific is shown in Fig. 15, for the event that occurred in Tonga. The theoretical travel time curves are superimposed on traces of vertical component, band pass filtered in 10∼80 mHz. Traces

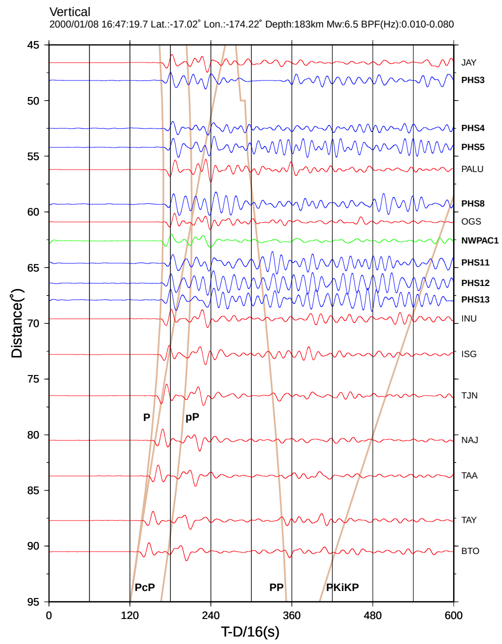

Fig. 15. Example record section for an event in Tonga. Traces are of vertical component. Theoretical travel time curves are superimposed. Blue, red and green traces are data from this LTOBS array (PHS3-13), land stations and the broadband OBS in the northwestern Pacific (NWPAC1), respectively. The travel time is reduced with a velocity of 16 km/s.

of the LTOBSs with the PMD sensors are rich in coda-like waves and look different from those of the others including the land stations and the BBOBS with the CMG-1T sensor. These coda-like waves may be an artifact due to a complicated transfer function of the sensor, but it is still under the investigation. The first arrival to NWPAC1 is apparently faster than those to other stations, with respect to the theoretical travel time curve, and this observation might indicate a direction-dependent velocity variation (anisotropy) of the upper mantle in the western Pacific region.

Our first experiment for the long-term seismic observation on the trans-Philippine Sea profile has thus been made almost successfully. The usefulness of this type of experiment for resolving the deep Earth's interior has become apparent even from the preliminary result. For further understanding of the mantle structure beneath the whole western Pacific, several long-term ocean bottom observations should be conducted systematically.

9 Long-Term OBEM Array Observation across The Philippine Sea

The Philippine Sea is one of the major marginal seas in the western Pacific and consists of three major basins; the West Philippine Basin, Shikoku-Parece Vela Basin, and Mariana Trough. Previous studies indicate that these basins have been formed by successive episodes of west to east opening (*e.g.*, Karig, 1971). As a part of the Ocean Hemisphere Project in Japan, we developed six Ocean Bottom ElectroMagnetometers (OBEMs) across the Philippine Sea during Dai-5 Kaikou-maru cruise in November, 1999; two OBEMs were in the northern West Philippine basin, two OBEMs in the northern Parece Vela Basin, and two OBEMs in the central Marina Trough (Fig. 16). The OBEMs measured two horizontal components of electric field and three components of geomagnetic field every one-minute for about eight months.

All the OBEMs were recovered during Shintatu-Maru cruise in July 2000 and the fairly high-quality data were obtained with some exceptions: **1)** The OBEM3 record is not available except for a period of one month, because the OBEM3 was flooded when it was recovered. **2)** The electric field record from OBEM1 is unstable in the initial period of about 50 days. **3)** The OBEM2 record has a data gap of 12 days. The electric field data have much larger drifts than the geomagnetic field data, which are due mainly to electrode problems.

We analyzed the data through the following procedure. First, we removed the drifts and then two horizontal components are rotated to obtain north and east components using the geomagnetic field data, because each OBEM had been set by a free fall. Figs. 17(a) and 17(b) show the record of each component of the OBEM. The geomagnetic field data are of very high quality, while the electric field data are contaminated by noise spikes, but still the effect of the magnetic storm is well visible. Then, we estimated the magnetotelluric (MT) impedance which is a frequency dependent transfer function from magnetic field to electric field that contains the information on electrical structure in the Earth. Five seafloor MT impedances with jackknife error bars are obtained from the original time series data using the robust remote reference method (Chave and Thomson, 1989). All the data show relatively small errors bar in a period range between 600 s and a few ten thousands, even though the electric field data are contaminated by the noise spikes.

Once the MT impedance is obtained, the electric field can be predicted from the magnetic field. For all the OBEMs the coherence between observed and predicted electric fields is fairly high for Ey but low for Ex. Thus, we use the Zyx element of the MT impedance, Z, to estimate 1-D conductivity structure. We use the MT impedance in a period range from 600 to 20,000 s for the estimation, because of the low coherence at periods shorter than 600 s and the possible contamination due to tidal effect at periods longer than 20,000 s. Finally, a 1-D conductivity structural model is obtained for each site by Occam's inversion (Constable *et al.*, 1987). Each structural model well explains the corresponding MT impedance obtained from the observation.

These preliminary structural models (Fig. 18) indicate that 1) the Philippine Sea plate with older crustal age has lower conductivity structure in general, and 2) the spreading axis Mariana Trough has extremely low conductive structure. Conductivity becomes lower in the order of the OBEM4, OBEM2, OBEM5, OBEM6, and OBEM1. The order is related to the crustal age except for the OBEM1. The OBEM4 is located on the oceanic crust, while the OBEM2, OBEM5, and OBEM6 are located on the old island arcs with their ages increasing in this order. The OBEM1 is located near the spreading axis of the Mariana Trough, showing extremely low conductivity structure. Results from the MELT experiment also show low conductivity structure beneath the southern East Pacific Rise at 17°S (Evans *et al.*, 1999). A low conductivity structure has also been reported beneath the Tahiti islands (Nolasco *et al.*, 1998). Thus, low conductivity structure may be a general feature beneath spreading axes and hot spots, where the uppermost mantle may be depleted in melt and volatile.

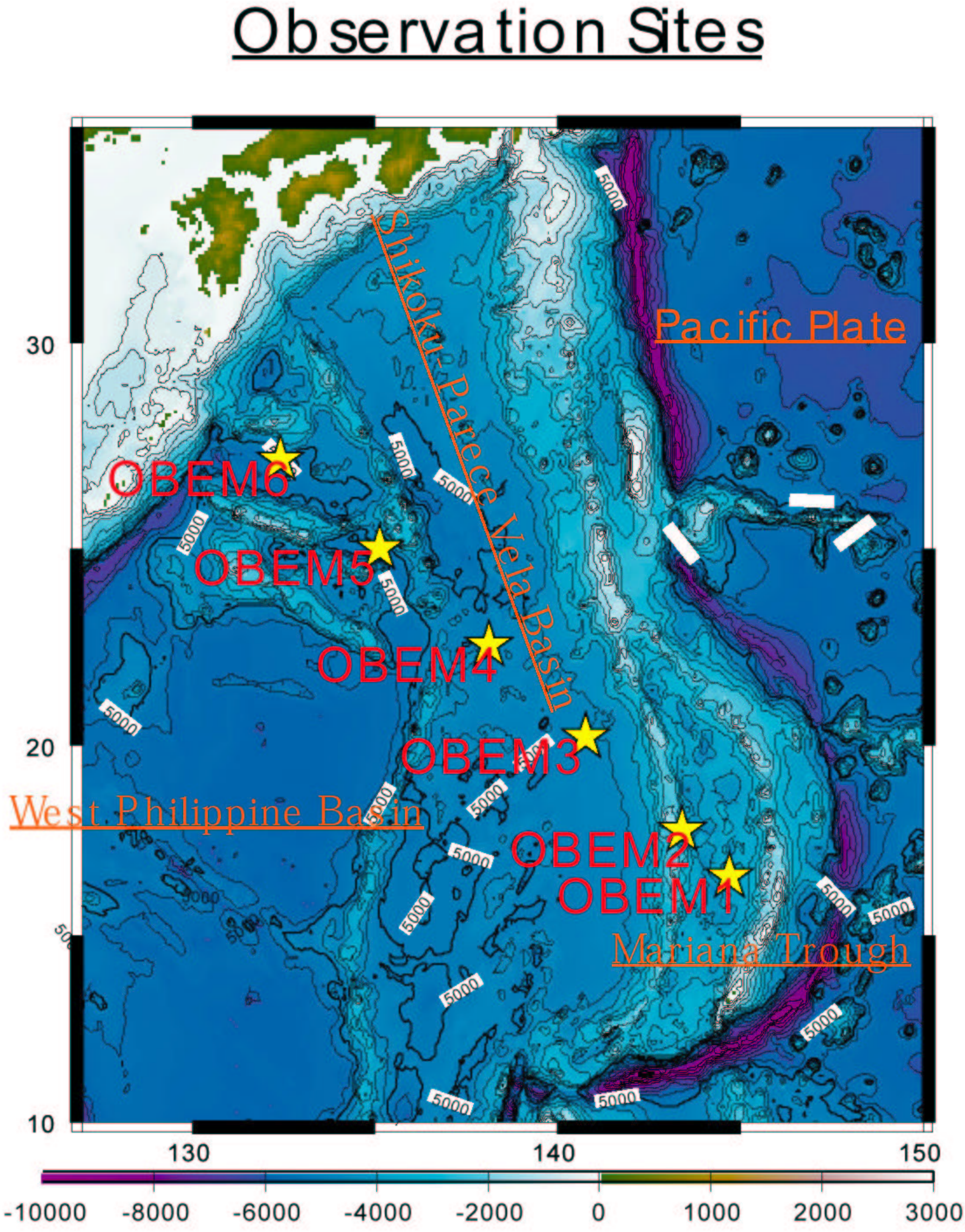

Fig. 16. Locations of OBEM sites (stars) in the Philippine Sea with their site names.

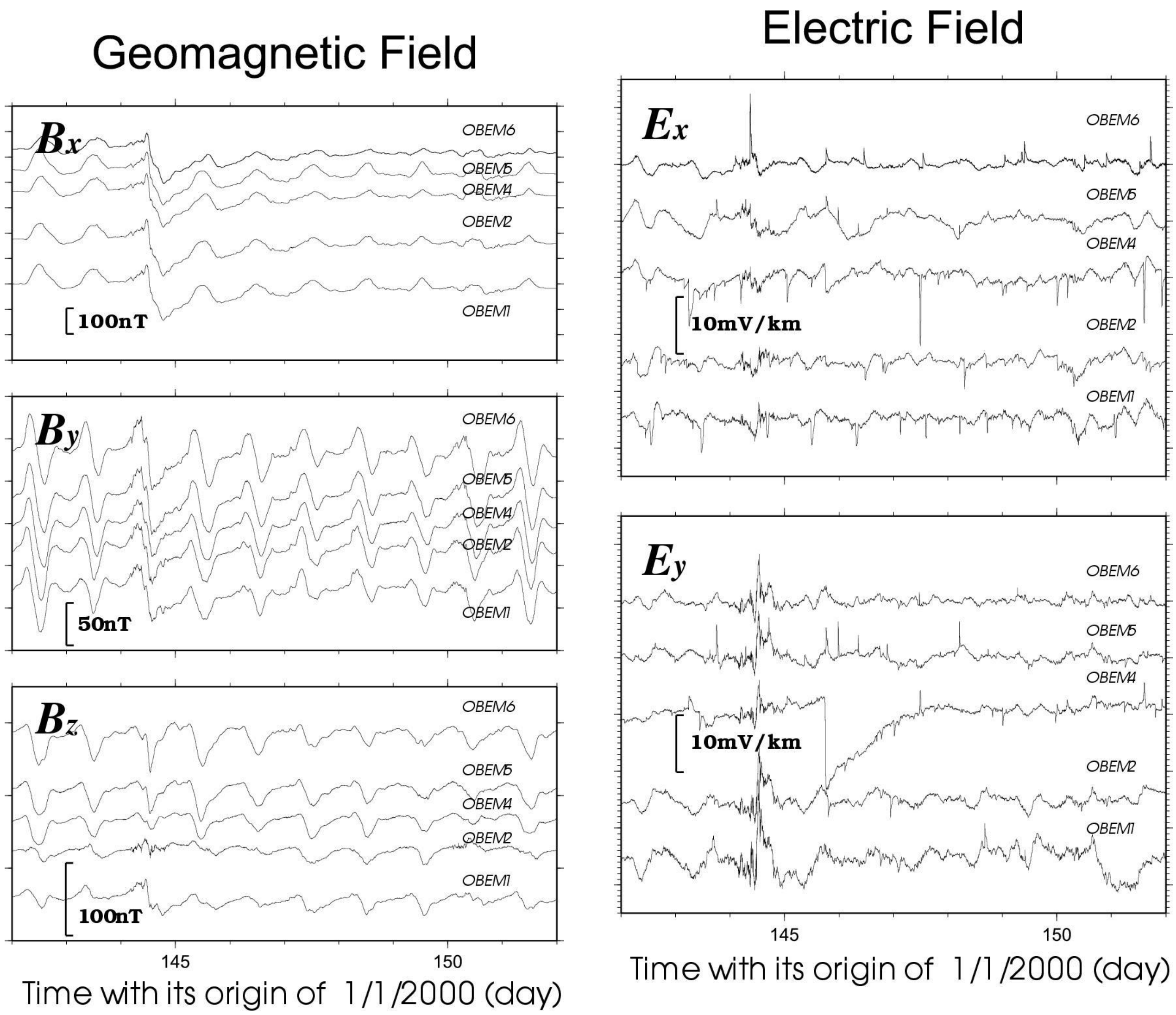

Fig. 17. The magnetic field (a) and the electric field (b) from each OBEM site is plotted against the time. Subscripts of x, y, and z are denote north, east, and downward components. Note that big magnetic storms are observed at 144th and 150th days.

Our analysis remains very preliminary, requiring further studies:
1) More carefully edited time series data should give an estimate of more precise magnetotelluric impedances, because the electric field data are contaminated by noise spikes.
2) Effect of seafloor topography should be taken in account to estimate more reliable conductivity structure using the method of Baba and Seama (2001).
3) Another survey with a more dense instrument array is required.
The conductivity model after these studies is expected to show vestiges of the tectonic evolution of the Philippine Sea in relation to the age difference of the lithosphere, and would provide a key to understand the mechanism of lithospheric evolution.

10 Development of Geodetic Measurement System on The Seafloor

Observation of crustal deformation on the seafloor is critical to understand the dynamic mechanism of subduction of an oceanic plate. Scripps Institution of Oceanography (SIO) was the first to develop precision acoustic transponders with sub-cm resolution in the ranging of 4∼5 km and combined them with kinematic GPS positioning. Their results of GPS/Acoustic (GPS/A) experiments about 100 km west of the coast of Oregon roughly agree with the plate motion in the geological time scale (Spiess et al., 1998).

We have been developing instruments for

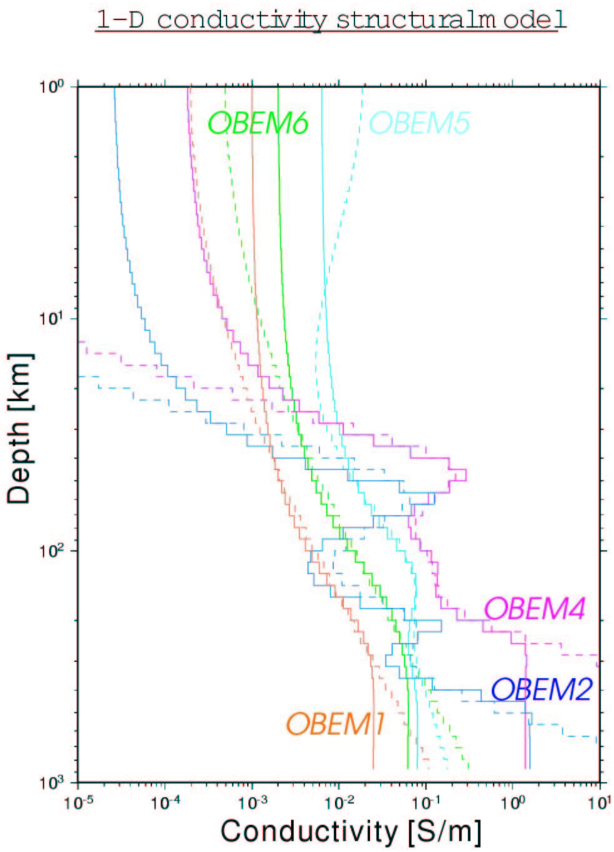

Fig. 18. Conductivity structural model of each OBEM site obtained by Occam's inversion (Constable *et al.*, 1987). The Occam's inversion gives smooth models by two ways, which are shown by solid (first derivative minimization) and dashed lines (second derivative minimization).

seafloor geodesy (Fujimoto *et al.*, 1998), and recently developed two acoustic transponder systems for GPS/A positioning by using the method of linear pulse compression under the OHP Program. One is the most up-to-date system for positioning on the deep ocean (6 km) developed jointly with SIO. Encouraged with the results of its sea trials, SIO produced 10 units of similar acoustic transponders and deployed them on the southeastern slope of Hawaii Island. Preliminary results show that the transponders can measure precise slant ranges over 14 km, indicating possibility of a GPS/A experiment on the seafloor of 10 km water depth. We plan to deploy three units of the acoustic transponders at 6000 m water depth (required slant range of about 9 km) on the seaward slope of the Japan Trench in 2001 for repeated seafloor positioning during the coming several years. We have also developed a simpler system for shallower seafloor and plan to deploy it on the landward slope of the Japan Trench in 2001.

11 Seismic Waveform Distribution System

Digital seismic waveform data are being accumulated in an accelerating ratio by various networks. Seismic data analysis using these huge amount of dataset is increasingly getting popular. For example, in the Western Pacific region, a large number of broadband digital seismographic stations are recently installed by various institutions (Fig. 19). If the data are appropriately gathered from these networks, they effectively constitutes a dataset from a very dense broadband network, and such a dataset should be very useful to determine high resolution seismic structures and seismic processes. However, in the current waveform distribution system, such studies require somewhat tedious procedures for collecting the waveform data of each data center with different interfaces.

Looking at the field of computer science, distributed object technology (The Object Management Group, 2000) is one of the most important technology in the modern system programming practice as it can handle a huge system in straightforward. Java RMI (Gosling and Steele, 1996; Sun Microsystems, 1999) is one of the most notably successful technologies to build a distributed object management system because of its highly expansiveness and security. We apply Java RMI technology to develop networked data distribution system providing a unified interface for various networks data. The overall structure is shown in Fig. 20, where the gray colored squares show objects. In this system, seismic waveform data are managed by respective data center so that they are always updated. Various request interfaces and data servers are networked via the Internet with each other. If a user send a request to a data request interface ("dispatcher", the left two gray squares in Fig. 20), the dispatcher dispatches the request to objects in various data center ("RMI server", the right two gray squares in Fig. 20), integrates the requested waveform data in internationally standard format (SEED format; Federation of Digital Seismographic Networks et al., 1993), and returns the resultant SEED volumes to the user. Thus, a user can download every latest seismic waveform data with a unified interface.

The current available dispatchers and RMI servers are shown in Table 1. Two applet dispatchers and six RMI servers are running. We have distributed many numbers of CD-ROM in which the application dispatchers software is stored. RMI servers are for PACIFIC21 (partly), BATS and IRIS

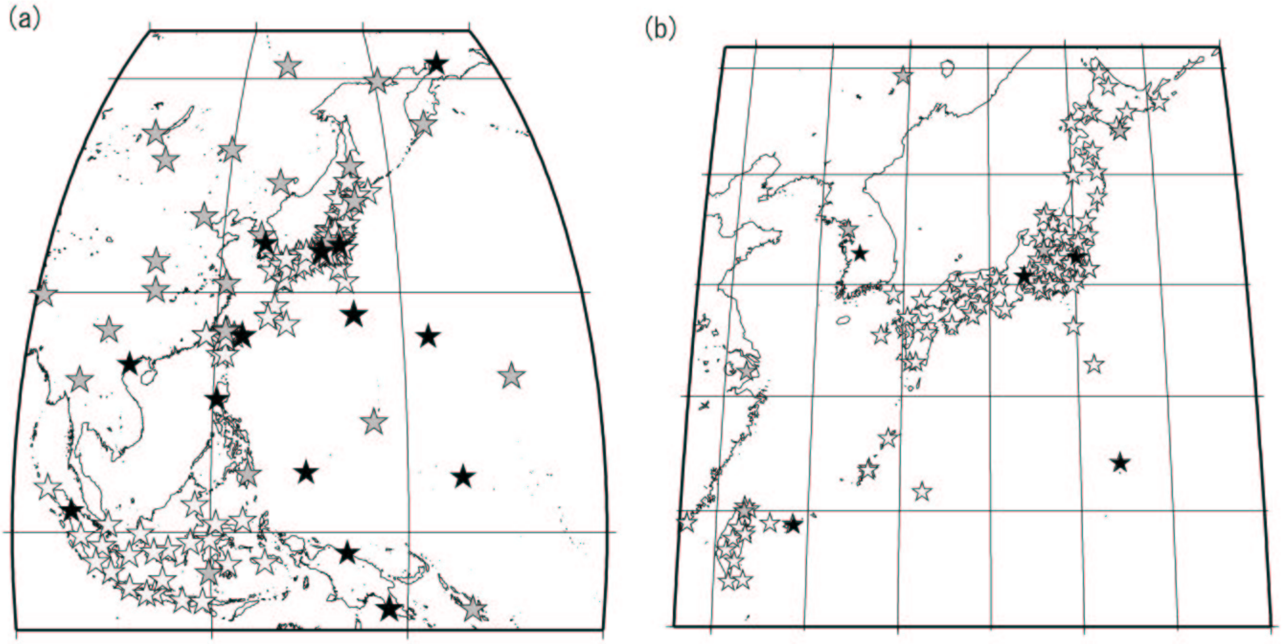

Fig. 19. Broadband seismographic station map (a) in the Western Pacific region, and (b) in Japan and Taiwan. Black stars indicate OHP network, gray stars indicate stations of IRIS network (IRIS/USGS, IRIS/IDA and IRIS/CDSN) and white stars indicate those of other networks.

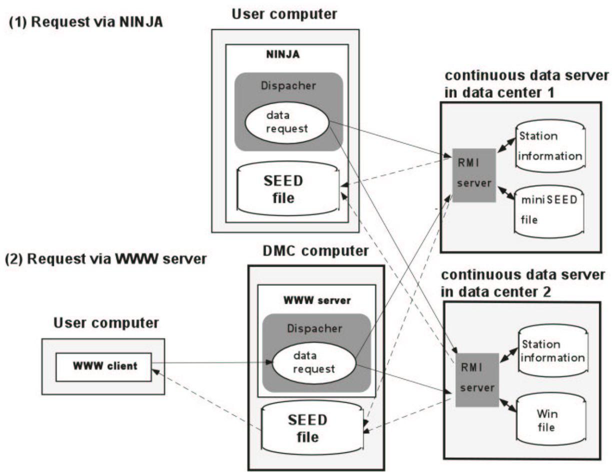

Fig. 20. Block diagram of our networked data distribution system. Gray squares indicate objects. "Win file" is a data file in Japanese domestic format.

<Dispatcher>

(1) Applet Dispatcher

URL	Location
http://ohpdmc.eri.u-tokyo.ac.jp/	Earthquake Res. Inst., Univ. Tokyo, JAPAN
http://odin.earth.sinica.edu.tw/	Inst. of Earth Sci., Academia Sinica, TAIWAN

(2) Application Dispatcher (NINJA)
We have distributed many numbers of NINJA CD-ROM.

<RMI Server>

Network	URL
PACIFIC21/OHP	ohpsrv.eri.u-tokyo.ac.jp
PACIFIC21/JMA	ocean.eri.u-tokyo.ac.jp
PACIFIC21/EOC	ohpsrv.eri.u-tokyo.ac.jp
PACIFIC21/GEOTOC	ocean.eri.u-tokyo.ac.jp
BATS	aeolus.earth.sinica.edu.tw
IRIS/IDA IRIS/USGS IRIS/CDSN	dmc.iris.washington.edu

Table 1. List of current dispatchers and RMI servers

data. Available PACIFIC21 data are OHP (formerly POSEIDON) and GEOTOC data. The domestic broadband data from JMA and EOC are also available. In the future, we have a plan to distribute every PACIFIC21 data. Providing a unified interface for various networks data greatly improves the convenience of users. Our communication method through firewall and automatic information synchronization mechanism between dispatchers does not require special setup by a user, thus our system is quite user friendly.

Java RMI is suitable for system expansion. It is straightforward to develop a new function, because it is architecture neutral and we do not have to prepare source codes for each platform (Sun Microsystems, 1999). Our information synchronization mechanism is also expansive. It is straightforward to increase the number of dispatchers and RMI servers because we do not have to change any setting of preexisting dispatchers nor RMI servers. Of course our system can be applied not only to seismological data but to any geophysical time series data including geomagnetic data, GPS data and superconducting gravimeter data. Thus our system is highly expansive.

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