Progressive Development of IFREE Marine Exploration Open Source Database

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Abstract Data pertaining to geophysical exploration have increased substantially and drastically in recent decades due to the acquisition of various global data sets. Both the accuracy of measuring devices and the associated analytical techniques are being constantly improved. We can obtain densely spaced, real-time data from underneath oceanic basements by using oceanographic observation networks. The IFREE (Institute for Research on Earth Evolution) plate dynamics research project has accumulated crustal data by using ocean-bottom seismometers (OBSs), a multichannel seismic (MCS) reflection system, bathymetry data by multi-beam swath system, potential data via a gravity meter and a shipboard towing proton and onboard three component magnetometers. In order to investigate tectonic structures and reveal the causal relationship between the occurrence of interplate earthquakes and the structures, these seismic data and geophysical data are processed and added to an internal database. In this paper, we propose the opening of a publication site by first targeting some of the velocity structural models obtained from OBS data analyses and MCS profiles after time-domain processing. The potential field data of gravity and magnetics along seismic lines are also provided through the user access point. This database can be useful and efficiently contributed for proponents to prepare scientific proposals for the Integrated Ocean Drilling Program (IODP).

Keywords: crustal structure, database, subduction, seismic survey, potential field data, bathymetry

1. Outline of IFREE crustal structure open source database

The IFREE plate dynamics database system is a part of the geophysical database project that commenced in 1997 and research programs in subsequent years. This database is accessible through the Internet and it can be used for a wide range of collaborative studies. We have obtained marine geophysical data from the following research programs: the Frontier Research Program for Subduction Dynamics (1997–2001), the first phase of the IFREE project (2001-2004), and the second phase of the IFREE project (July 2004–). The crustal structure database has been designed specifically for the following purposes: assist in the understanding of plate dynamics and construction of three-dimensional crustal structure models, clarify the seismogenic mechanism of great subduction zone earthquakes, and construct long-term earthquake recurrence models (Fig. 1). This database contains reflection and refraction seismic data, bathymetry and ship track locations, gravity data, and marine magnetic anomaly data acquired by deep-sea research vessels. The eight-year surveys yielded a considerable amount of datasets that can be released in the public domain as an open source database (Figs. 1b, 2, 3, 4, 5). Dataset obtained by Jamstec research vessels are closed for two-year moratorium period based on the Jamstec database site policy. The data that could be accessed were multichannel seismic reflection data (MCS), refraction and wide-angle seismic data acquired by ocean-bottom seismometers (OBSs), marine magnetic data, and gravity data. In this paper, we introduce the crustal structure database site and provide examples of some geophysical data in order to evaluate the evidence of pre- or post-seismic deformation.

2. Description of newly acquired data

The JAMSTEC operates five research vessels for 200 days per year. A list of geophysical data items, along with specifications, that were newly acquired by the JAMSTEC is shown in Table 1. The JAMSTEC Computer and Information Office (JCIO) routinely records, edits, and collates onboard digital marine geophysical data such as cruise logs, navigation data sampled every one second (including the time, position, water depths, gravity, total magnetic force, wind direction and velocity), temperature, water temperature, shipboard speed, and multi-beam swath data. These are recorded on digital media and registered in the JAMSTEC geophysical database; then, a part of these data is made available on the public domain (Kido et al., 2001).

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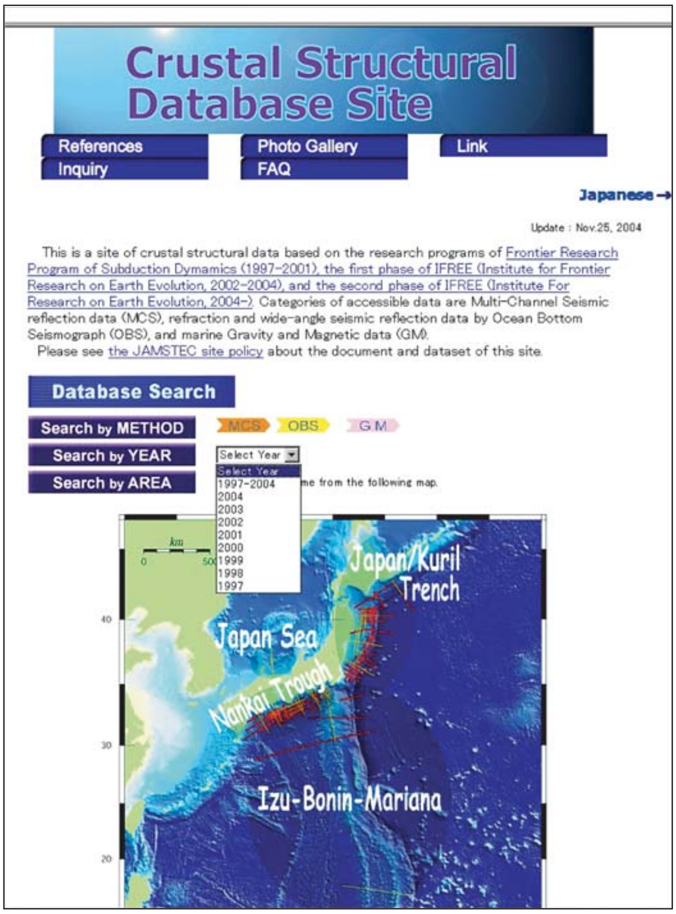
(a)



(b)

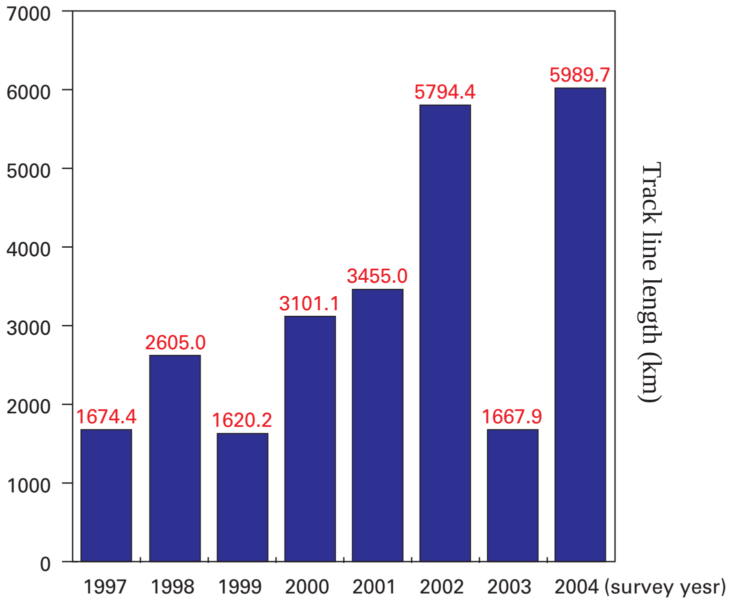


Figure 1: (a) : Top-page image of the crustal structure database site.
The URL of the Japanese site is
http://www.jamstec.go.jp/jamstec-j/IFREE_center/
The URL of the English site is
http://www.jamstec.go.jp/jamstec-e/IFREE_center/index-e.html
(b) : Database stores the whole lengths of crustal structure surveys since 1997.

Figure 2: List of the crustal structure cruise data obtained from 1997 to so far; the survey year, cruise name, survey area, name of the chief scientist, and survey period are included.
The URL of the Japanese site is
http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruisedata_all.html
The URL of the English site is
http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruisedata_all-e.html

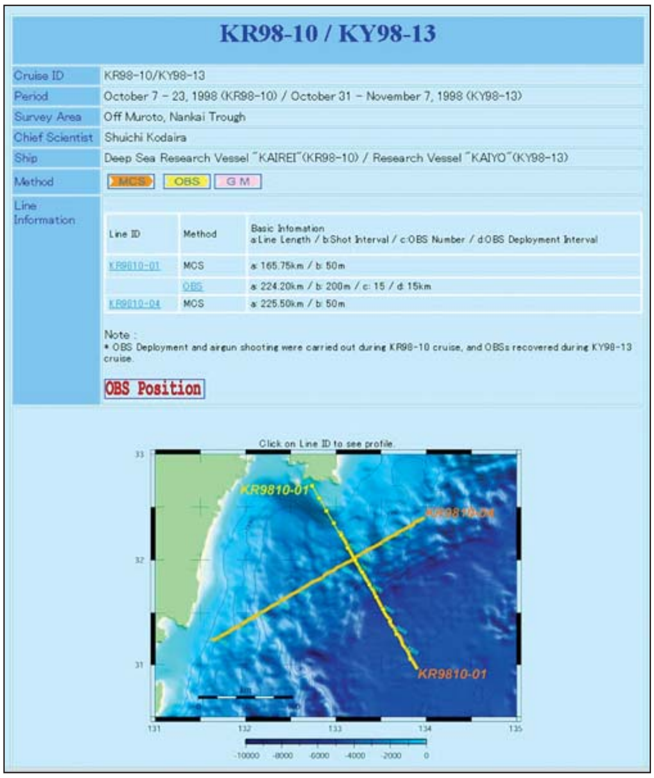


Figure 3: Description of each cruise item and track chart are listed on. Track lines show seven-year MCS and OBS wide-angle seismic surveys conducted by R/Vs Kairei and Kaiyo including the locations where OBSs were deployed. The numbers indicated in the track charts are linked with a page containing seismic sections. Topography data were obtained from JTOPO30 by the MIRC (Marine Information Research Center, Japan Hydrographic Association).
The URL of the Japanese site is
http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruise_data/KR98-04-1.html
The URL of the English site is
http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruise_data-e/KR98-04-e.html

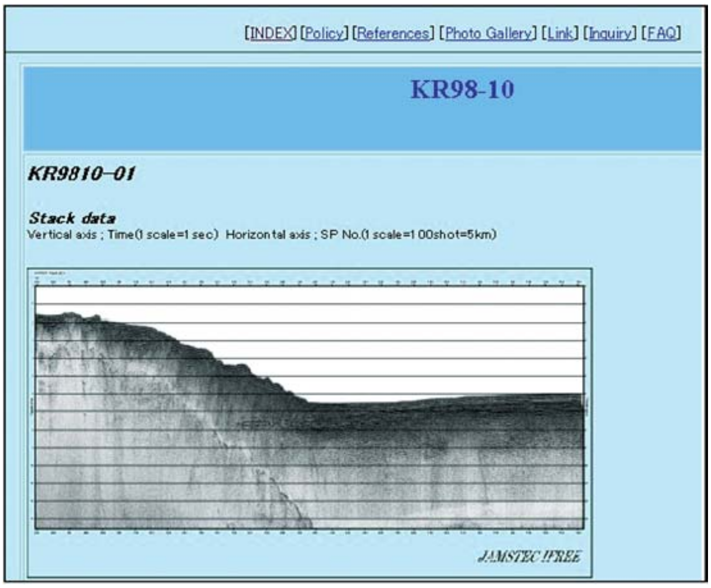


Figure 4: An example of the MCS section along the KR9810-01 line. The displayed MCS sections are combined to perform a time-migrated analysis. The descriptions are as follows:
* Line parallel to the trench axis: Right = North or East, Left = South or West
* Line crossing the trench axis: Right = South or East, Left = North or West
* Vertical axis: Two-way time (1 scale = 1000 ms)
* Horizontal axis: SP number (1 scale = 100 SP = 5 km) or CDP number (1 scale = 1000 cdp = 12.5 km)

The URL of the Japanese site is
http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruise_data/KR98-10section.html#1
The URL of the English site is
http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruise_data-e/KR98-10section-e.html#1

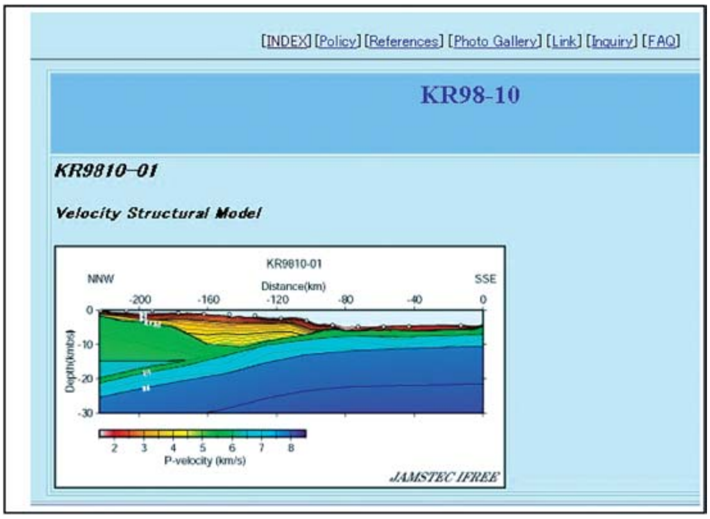


Figure 5: An example of the P-wave seismic velocity model along the KR9810-01 line. The color index shows the P-wave velocity contrast.
The URL of the Japanese site is
http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruise_data/KR98-10vmodel.html
The URL of the English site is
http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruise_data-e/KR98-10vmodel-e.html

Table 1: Newly acquired data list. Marine geophysical survey data stocked in the IFREE geophysical database.

No.	Items. (*Asterisk indicates data in the open site)		Data description and Survey specification (by mainly R/V Kairei)
1.	Seismic Data*	Multi-channel reflection data (MCS)*	MCS data acquisition system : • Streamer cable: Syntron 24-bit dgital streamer, 156 channels (standard), 204 channels (max) • Air gun: Bolt par airgun Model 1500, 12000 cu. in. (200 liter) in total • Recording system: Syntron SYNTRAK 960 • Navigation system: Concept SPECTRA, DGPS • Processing software: ProMax and iXL (JGI)
		OBS (Ocean Bottom Seismograph) refraction data*	OBS recording system: • Air gun: Bolt par airgun Model 1500, 12000 cu. in. (200 liter) in total • OBS: pop up retrieval type within 6000-m water depth Three component (one vertical and two horizontals) velocity sensitive geophones (4.5 Hz) and a hydrophone • Recording system: 16 bit A/D converter with 100 Hz sampling on DAT or HDD
2.	Bathymetry Data / Multi-narrow beam		Seabeam 2000, HS10, Gridded data through SeaView tool SEA BEAM 2112 by SeaBeem Instruments
3.	Gravity Data*	Shipboard gravimeter*	BODESEEWERK KSS31 by Fuguro co.ltd. • measurement accuracy : 1 mGal • drifting : 3 mGal/Month • measurement range : 10000 mGal S-63 LaCoste & Romberg
		Portable gravimeter	CG-3M by SINTREX Co. ltd. • limit of resolution : 0.01 mGal • minimum operating range : 7000 mGal • repeatability/standard deviation : less than 0.01 mGal/day
4.	Magnetic Data	Total magnetic field measurement	Proton magnetometer
		Three component magnetic data	Shipboard three component magnetometer : SFG1214 by Terra Technica Co. ltd. instrumentation • limit of resolution : 1 nT • precision : less than 100 nT • measurement range : less than ± 100000 nT vertical gyroscope • measurement accuracy : ± 0.2° • limit of resolution : 0.0055°

Both reflection and refraction experiments were conducted by IFREE geophysical researchers using R/Vs Kairei and Kaiyo for 120 days per year. Controlled seismic sources were fired into a MCS streamer and OBSs along the main track and perpendicular lines. Reflection surveys were conducted to delineate seismic formations and fault zones in the topmost part of the crust. Wide-angle refractions were also recorded by OBSs, which provide good measurements of the seismic structure with high heterogeneity. During seismic surveys, swath bathymetry, gravity data, and magnetic data were also automatically recorded. In the IFREE geophysical database, such crustal structure data and potential field data (i.e., gravity and marine magnetic anomalies) for the Japan region are cross-referenced to facilitate the construction of three-dimensional models.

2.1 MCS data

The MCS survey system consists of an air-gun array and streamer cable with hydrophone that is towed by the ship's stern. A seismic sonic wave produced from the air-gun array propagates to the seafloor and the underlying ocean crust. Seismic waves are reflected from the ocean bottom and sub-seafloor reflecting interfaces. The long streamer of hydrophones records these reflected waves. This enables us to image seismic structures at depths of nearly 20–30 km beneath the ocean bottom.

http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/MCS_all-e.html

2.2 OBS data

One of the objectives of the crustal structural expedition is to obtain P-wave velocity structures underneath the ocean bottom. In this study, seismic data used here are deep-penetrating refraction waves and wide-angle reflection waves generated by the large air-gun array system. All OBSs are settled on the ocean bottom and positioned by using a real-time super shot baseline acoustic positioning system with an accuracy of 1–3% of water depth. Since we require a high-resolution seismic image, a super-densely deployed OBS array with spacing of a few kilometers is preferred. These seismic methods that use OBSs can be used for understanding the deeper structures.

http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/OBS_all-e.html

2.3 Gravity measurement data

Shipboard gravity measurements were carried out using KSS-31 and S-63 gravimeters on R/Vs Kairei and Yokosuka, respectively. These data are filtered and transferred along with navigation data via an onboard local area network to a workstation where they are recorded. Before and after the cruise, the gravimeters are calibrated with a portable gravity measurement system at a steady point of the JAMSTEC pier. The data, which are finally entered into the geophysical database, are extracted from data sampled for 1 s to 15 min. The gravity anomalies lead to local topography and density variations as well as inhomogeneities (unit: mGal). We observed large topographic features with low-density crustal roots. The overloaded mass crustal block produces a positive gravity anomaly and, in contrast, the low-density roots produce a negative anomaly.

http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/GM_all-e.html

2.4 Marine magnetic data

The marine magnetic surveys revealed strong magnetic patterns, dipolar anomalies, and lineations, which indicate continuous parallel zones of positive and negative anomalies. These magnetic bands are useful for determining the age of the oceanic crust. Towing a proton magnetometer at a distance of about 300 m from the ship's stern yields geomagnetic total field measurements, and these measurements are made at 20–30 s intervals. The data quality is checked via real-time monitoring in the onboard laboratory. The proton magnetometer records the absolute value of the geomagnetic field. A shipboard three-component magnetic (STCM) measurement system provides three directed intensities with a high resolution of directions. These data have been registered in the geophysical database, where they have been combined with simultaneously acquired swath bathymetry and gravity data in order to facilitate interpretation.

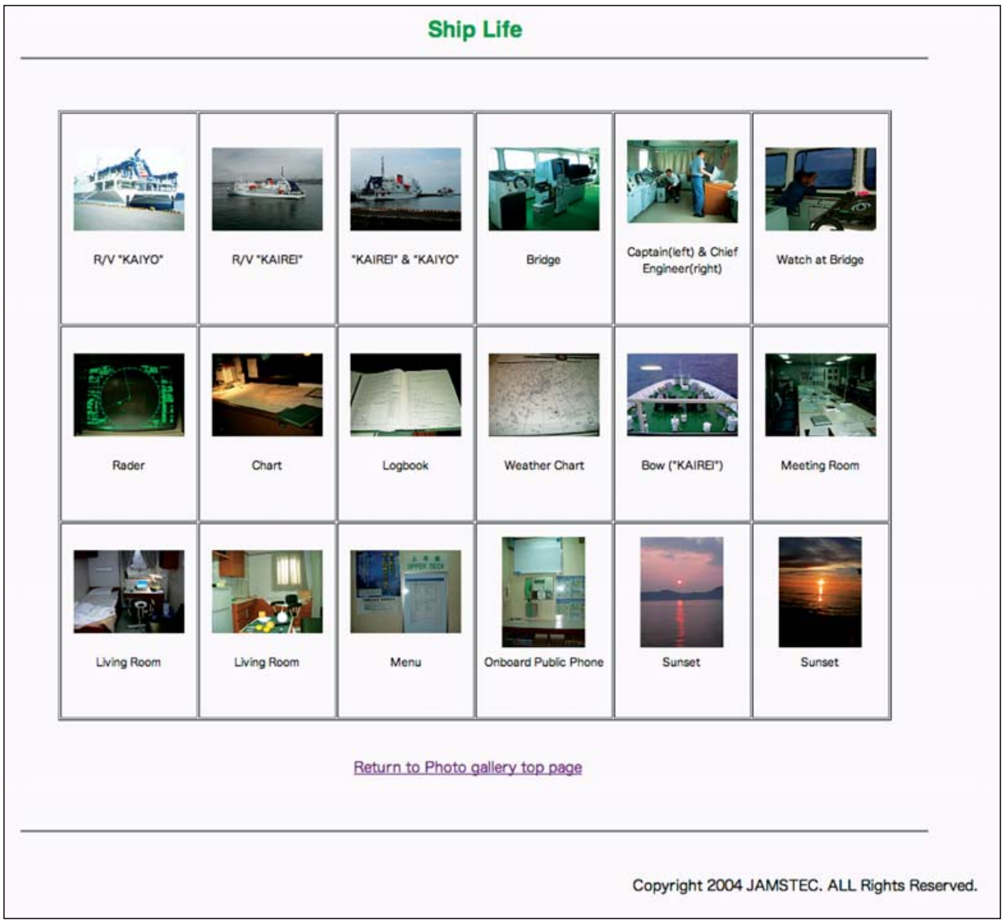
3. Example of database utilization

In this section, we present an example of the utilization of the database site. The 2003 Off-Tokachi Earthquake with Mw 8.0, believed to be a megathrust earthquake, occurred on September 26, 2003 (Yamanaka and Kikuchi, 2003). The JAMSTEC R/V Kairei was deployed off Tokachi in December 2003 for conducting the MCS survey and multibeam swath mapping survey to determine any traces leading by the Off-Tokachi Earthquake. We have already conducted geophysical line/box surveys including swath bathymetry, gravity, total and three-component magnetics, MCS survey, and submersible investigations for several years; a part of the results from these surveys are included in the public domain in the geophysical database on both the JAMSTEC local website and the crustal structure website (Kido et al., 2002). Fig. 7 shows a bathymetric image obtained off southeastern Hokkaido by compiling several multi-narrow bathymetry data acquired by the JAMSTEC and Hydrographic and Oceanographic Department of the Japan Coast Guard in the years of 2001 to 2004. Extracted corridors chart by whole complied bathymetric data and backscattering images shown in Fig. 8 were acquired three years before and three months after the 2003 earthquake; they were obtained for the same lines and with the same specifications. Several differences in topographic features are obvious but still in arguing from the aspect of accuracy of multi-narrow survey (Kido et al., 2005). As a result of the time lapses in the MCS survey, a variation in the reflectivity was observed near the source area (Tsuru et al., 2005) (Fig. 9).

4. Future prospects

A large amount of various data sets are stored and registered in both the JAMSTEC (JCIO) and plate dynamics database systems. Since decades of data are accumulated, the database system can pose challenges while finding and evaluating any evidence of pre- or post-seismic deformation. These are only small amount of examples of a specific area. In general, the seismic data occupy a huge volume of data space, therefore, one of the next step of the database system is to transport smoothly, widely, simultaneously, and efficiently through narrow network communications. We should

(a)



(b)

References (Nankai Trough)

Authors	Title	Journal	Year	Area
Kido, Y. and T. Fujiwara	Regional variation of magnetization of oceanic crust subducting beneath the Nankai Trough	Geochemistry, Geophysics, Geosystems, Vol. 5, Q03002, doi:10.1029/2003GC000649	2004	Nankai Trough
Kodaira, S., T. Iidaka, A. Kato, J.-O. Park, T. Iwasaki, Y. Kaneda	High pore fluid pressure may cause silent slip in the Nankai Trough	Science, 304, 1295-1298	2004	Nankai Trough
Kodaira, S., Nakanishi, A., Park, J.-O. , Takahashi, N., and Kaneda, Y.	What control segmentations of mega-thrust earthquake in the Nankai Seismogenic Zone: a Review of high resolution wide-angle seismic surveys	Bull. Earthq. Res. Inst, 78, 175-183	2003	Nankai Trough
Kodaira, S., Nakanishi, A., Park, J.-O., Ito, A., Tsuru, T., and Kaneda, Y.	Cyclic ridge subduction at an inter-plate locked zone off central Japan	Geophys. Res. Lett., 30 (6), 1339, doi:10.1029/2002GL016595	2003	Nankai Trough
Park, J.-Oh, Moore, G., Tsuru, T., Kodaira, S., and Kaneda, Y.	A subducted oceanic ridge influencing the Nankai megathrust earthquake rupture	Earth and Plan. Sci. Lett., Vol. 217, 77-84	2003	Nankai Trough
Takahashi N., Kodaira, S., Park, J.-O., and Diebold, J.	Heterogeneous structure of western Nankai seismogenic zone deduced by multichannel reflection data and wide-angle seismic data	Tectonophys., Vol. 364, No.3, 167-190	2003	Nankai Trough
Kodaira, S., E. Kurashimo, J. -O. Park, N. Takahashi, A. Nakanishi, S. Miura, T. Iwasaki, N. Hirata, K. Ito, and Y. Kaneda	Structural factors controlling the rupture process of a megathrust earthquake at the Nankai trough seismogenic zone	Geophys. J. Int., 149, 815-835	2002	Nankai Trough
Nakanishi, A., H. Shiobara, R. Hino, J. Kasahara, K. Suyehiro, and H. Shimamura	Crustal structure around the eastern end of coseismic rupture zone of the 1944 Tonankai earthquake	Tectonophysics, 354, 257-275	2002	Nankai Trough
Nakanishi, A., H. Shiobara, R. Hino, K. Mochizuki, T. Sato, J.Kasahara, N. Takahashi, K. Suyehiro, H. Tokuyama, J.Segawa, M. Shinohara, and H. Shimamura	Deep crustal structure of the eastern Nankai trough and Zenisu ridge by dense airgun -OBS seismic profiling	Mar. Geology, 187,	2002	Nankai Trough

Figure 6: Other service providing the crustal structural database. (a) : Photo gallery categorized by OBS, MCS, underway geophysics operations and onboard life. (b) : Publication list related to crustal structure researches on a fiscal year basis or on research filed basis.

Table 2: (a) Number of registered user at the time of December 2, 2005. Since the site was opened for the general public in May, 2004, there are 18 applications registered and 15 received digital dataset. Three of them could not able to received our dataset cause of non related data request, net work communication error, and out of data policy.
(b) Distribution list of applied persons affiliation.
(c) Item list of requested data. We can provide poststack, prestack, navigation, detail description of MCS, velocity model, wave form, detail description of operation of OBS, and potential data (gravity and magnetic anomaly dataset).

(a)

Number of registered user (2005/12/02)		
Year	Month	No. person
2004	August	2
	September	2
	October	4
	December	1
2005	February	2
	April	4
	June	2
	July	1
	October	2
Total		18 (15)

(b)

Application person's breakdown	
Company persons (include it in NME)	3
Researchers (include it in JAMSTEC)	3
College professors (include it in technical staff)	6
Students (four doctor's and two master's course people)	6

(c)

Items of requested data		
MCS	16	Poststack 8 Prestack 2 Navigation, others 5
OBS	8	velocity model 5 Wave form (formatted as SEG-Y, others) 2
Potential data (gravity and magnetics)	5	

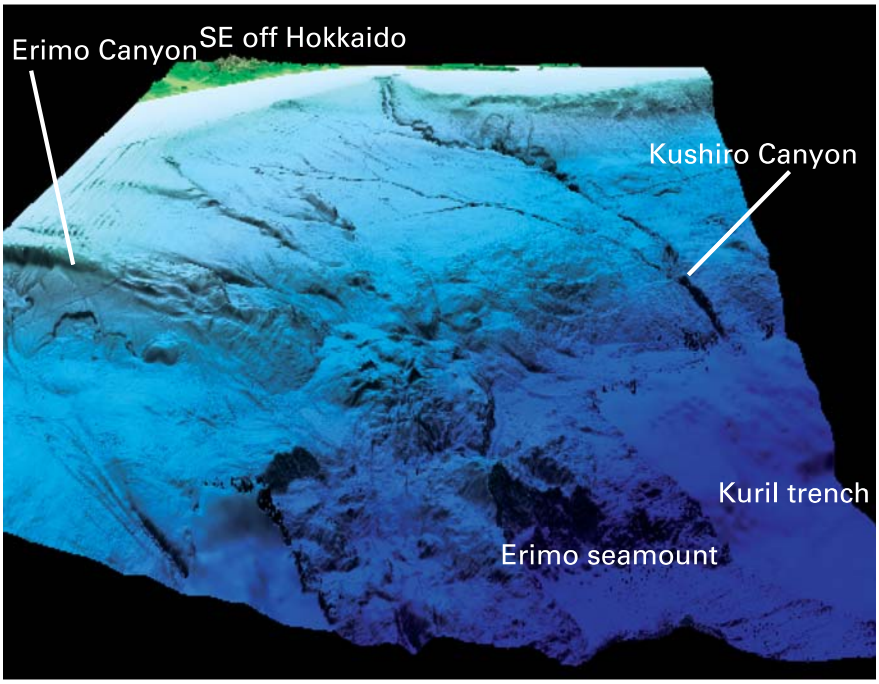


Figure 7: Seafloor topography of off-southeastern Hokkaido, Japan. A part of the bathymetry data was provided by the Hydrographic and Oceanographic Department of the Japan Coast Guard. The horizontal to vertical ratio is 1:10.

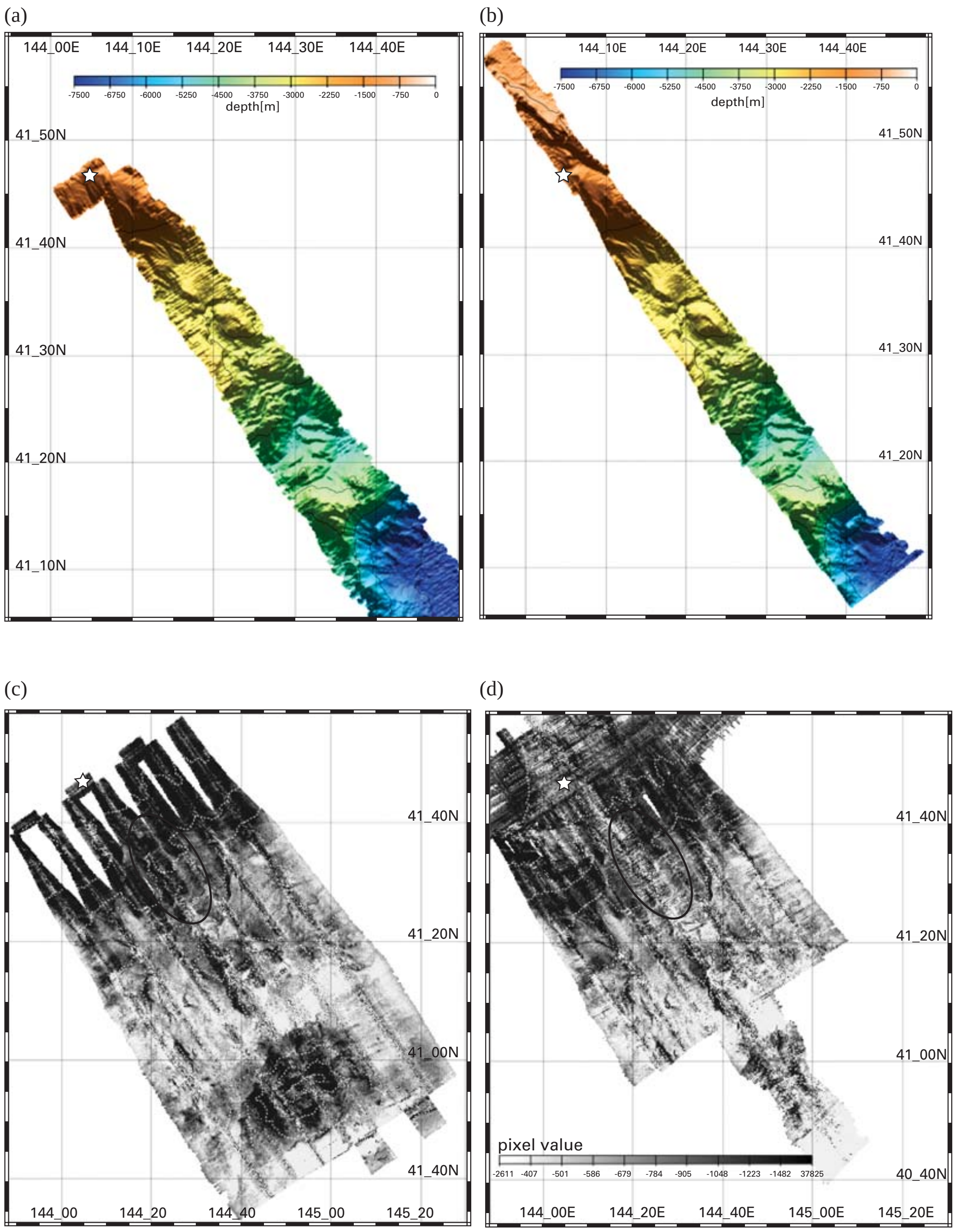


Figure 8: (a) Corridor bathymetry image of the three years before the 2003 Off-Tokachi Earthquake. (b) Corridor bathymetry image of the three months after this earthquake. (c) Backscattering image of the three years before the earthquake. (d) Backscattering image of the three months after the earthquake. White asterisks denote the epicenter of the earthquake.

choose an appropriate scheme to maintain the security level during data transportation. The crustal structure database containing various datasets will enable us to perform multifaceted studies of geophysical properties of specific oceanic regions. We are planning to connect other local databases such as the JAMSTEC geophysical database, rock sample database, and seismicity database to the global network system. We expect the flow of information through such a database to be bidirectional. In other words, while data from the database are used as the basis for numerical simulation of the plate behavior or seismic activity, the results of such an analysis should be fed back into the database so that future geophysical surveys can be planned and executed with better reliability. This iterative approach will enable us to firmly establish the reliability of the database and its associated models.

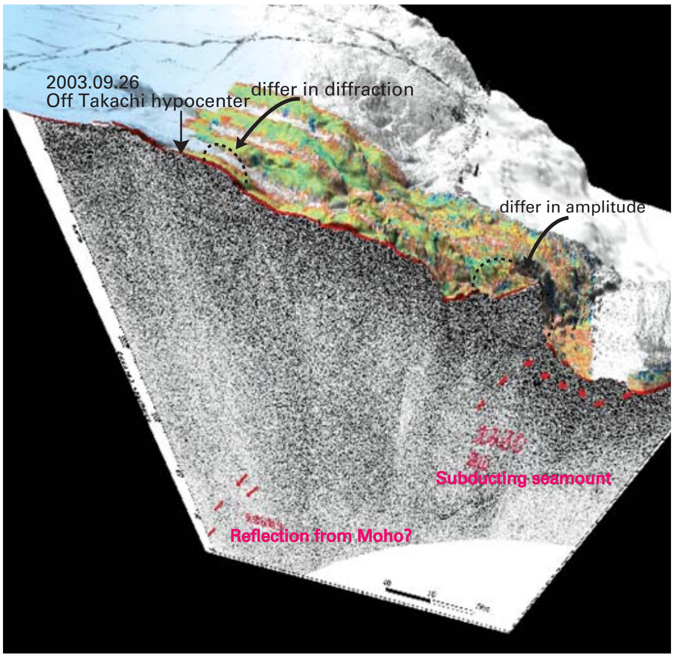


Figure 9: 3D view of the seafloor topography and MCS seismic section of the investigated region. Red and blue color lines on the bathymetry image denote the differences between the observations made three years before and three months after the earthquake (±15 m) (Kido et al., 2005). Differences in both the diffraction and amplitude are observed by the MCS survey (Tsuru et al., 2004). The MCS section shows strong reflection patterns at the 2003 Off-Tokachi Earthquake hypocenter, which might be reflections from the Moho and the subducting seamount about 5 km below the seafloor (right-hand side).

Acknowledgments

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References

Kido, Y., M. Toizumi, T. Tsuru, and Y. Kaneda, Multi-beam bathymetric survey off Tokachi challenging to evaluate evidences of the pre/post seismic deformation—Development of IFREE Geophysical Database System, *Geoinformatics*, Vol. **16,** 1, pp.17–26 (2005), (in Japanese).

Kido, Y., Y. Kosumi, A. Nakanishi, T. Tsuru, and Y. Kaneda, Geophysical features on subducting seamounts at the junction of Japan and Kuril Trenches—Using potential anomalies and admittance functions, *Geoinformatics*, Vol. **13**, No. 3, pp. 141–151 (2002), (in Japanese).

Kido, Y., T. Tsuru, J-O. Park, T. Higashikata, Y. Kaneda, and Y. Kono, Three dimensional overview of the Japan Trench—An example of utilization of the Frontier Database System, *Computers & Geosciences*, Vol. **27**, pp. 43–57, (2001).

Tsuru, T., J.-O. Park, Y. Kido, A. Ito, Y. Kaneda, T. Yamada, M. Shinohara, and T. Kanazawa, Did expanded porous patches guide rupture propagation in 2003 Tokachi-oki earthquake?, *Geophys. Res. Lett.*, Vol. **32**, No. 20, L20310, 10.1029/2005GL023753, (2005).

Yamanaka, Y. and M. Kikuchi, Source process of the recurrent Tokachi-oki Earthquake on September 26, 2003, inferred from teleseismic body waves, *Earth Planets Space*, **55**, e21–e24 (2003).

Wessel, P. and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS Trans. AGU*, **76**, 329, (1995).

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