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BROAD-BAND AND WIDE DYNAMIC-RANGE SEISMIC OBSERVATIONS WITH AN STS-SEISMOGRAPH AT SYOWA STATION, EAST ANTARCTICA

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Abstract: Broad-band and wide dynamic-range seismic observations with a three-component Streckeisen seismometer (STS-1V, -1H) have been carried out at Syowa Station, East Antarctica since April 1989. A digital acquisition system for broad-band (BRB) velocity signals was started from May 1990, for the purpose of providing valuable data for the study of global seismology. In this paper, the seismic observations with STS are presented during the winter period of the 33rd Japanese Antarctic Research Expedition (JARE-33; from February 1992 to January 1993). In practice, the current observation system, hypocentral distribution of the detected events and some examples of recorded digital waveforms are presented. A possibility to detect a weak long-period signal, such as that of the free oscillation of the Earth, is also mentioned in relation to the observations with the superconducting gravimeter at Syowa Station which have been carried out since March 1993.

1. Introduction

A three-component Streckeisen seismometer (STS-1V, -1H) was installed and analog monitoring was started at Syowa Station, East Antarctica (69.0°S, 39.6°E), in April 1989 by the 30th Japanese Antarctic Research Expedition (JARE-30) (MURAKAMI and KAMINUMA, 1991). The broad-band and wide dynamic-range digital seismic recording system of the BRB (broad-band) velocity signal was started in May 1990 by JARE-31 (NAGASAKA *et al.*, 1992). The installation of the broad-band digital seismographs at Syowa Station was based on the recommendation of the Working Group of Solid Earth Geophysics of the Scientific Committee on Antarctic Research (SCAR). The most significant meaning of observations at Syowa Station, at the high southern latitude of 69°S with broad-band digital seismographs, is to provide high quality data for the study of global seismology.

The location of Syowa Station has a great deal of geometrical advantages because of its high southern latitude, where the broad-band seismic stations are rarely distributed. ROULAND *et al.* (1992) pointed out the existence of undetected earthquakes in the southern hemisphere by using long-period GEOSCOPE data. It is also pointed out that the magnitude threshold of earthquake detection has a gradual increase with increasing southern latitude (RINGDAL, 1986). Figure 1a shows the global distribution of digital broad-band seismograph stations in November 1992 (modified after IASPEI REPRESENTATIVE TO FDSN WORKING GROUP I, 1992). Several stations among them belong to Federation of Digital Seismographic Networks (FDSN). Syowa Station is located

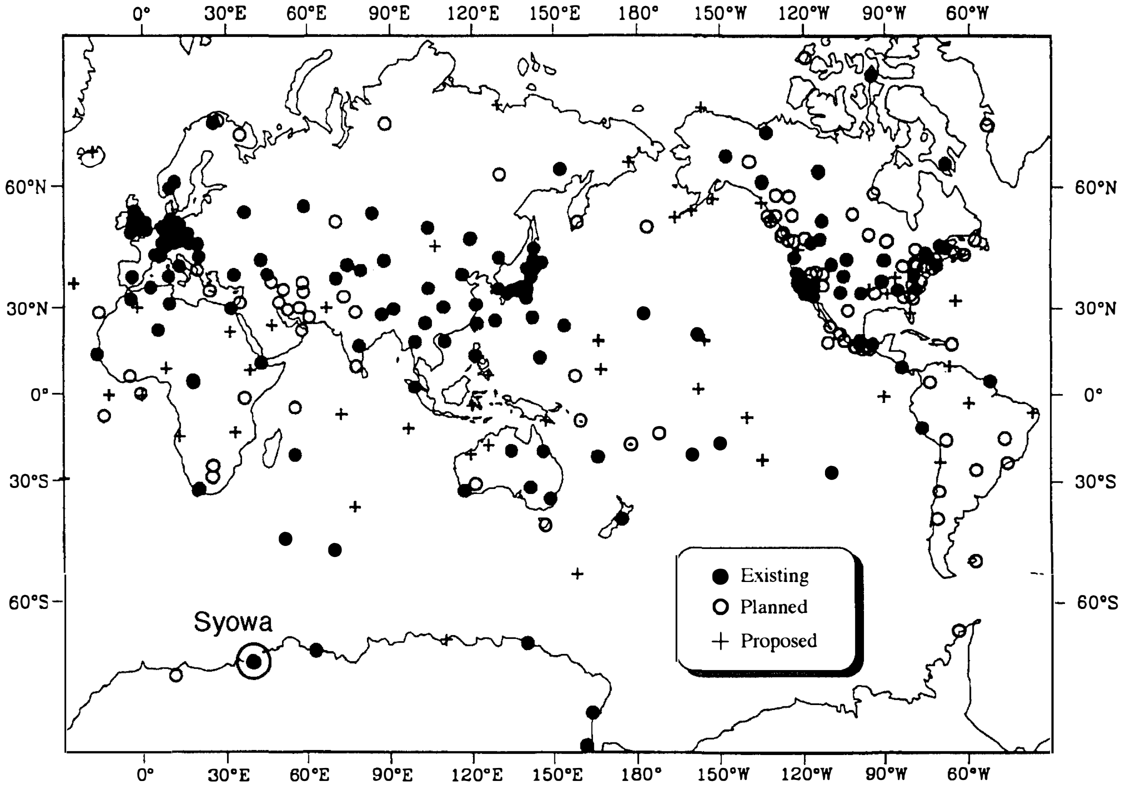

Fig. 1a. The global distribution of the current inventory of digital broad-band seismograph stations in November 1992. Several stations among them belong to the Federation of Digital Seismographic Network (FDSN) (modified after International Association of Seismology and Physics of the Earth's Interior (IASPEI) Representative to FDSN Working Group I, 1992). The status of each station is as follows : solid circles ; existing stations, open circles ; planned stations, cross ; proposed stations. Syowa Station is represented by an open circle with a dot.

about 1000 km from the nearest seismic observation station (Mawson Station, Australia), on the continental margin of EastAntarctica. Moreover, Syowa is located about 2500 km away from the Crozet Island station of the GEOSCOPE project, which is located in the south-western part of the Indian Ocean (ROMANOWICZ *et al*., 1991). Figure lb shows the distribution of digital broad-band seismograph stations in Antarctica in November 1992 (modified from the same paper used in Fig. 1a). Moreover, Syowa Station has an important role as one of the stations of the Japanese Pacific Orient Seismic Digital Observation Network (POSEIDON) project (SHIMAZAKI *et al*., 1992), which is the Japanese contribution to the FDSN research program.

2. Observation System

The location of facilities concerning seismological and geophysical observations at Syowa Station is presented in Fig. 2. The three component sensors and the STS feedback electronics have been installed beside the three-component of long-period (LP) seismometer (PELS type ; with the natural period of 12 s) and the short-period (SP) seismometer (HES type ; with the natural period of ls) in the seismic vault. The SP and LP seismometers

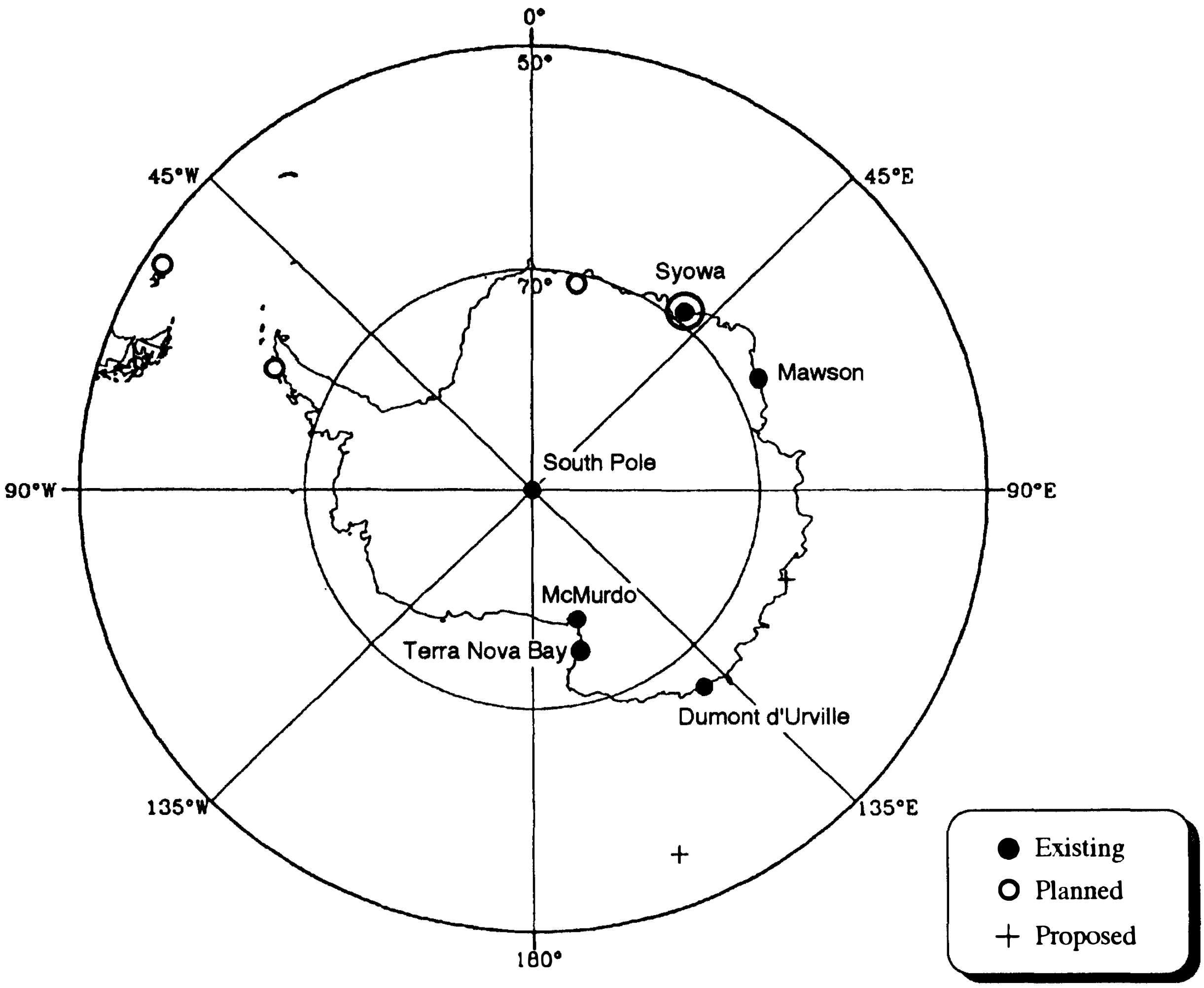

Fig. 1b. Distribution of the current inventory of digital broad-band seismograph stations in Antarctica in November 1992 (modified after IASPEI Representative to FDSN Working Group I, 1992). The status of each station is the same as in Fig. 1a.

have been operating since 1961 and 1967, respectively (KAMINUMA *et al.*, 1968). This seismic vault was rebuilt in March 1970 (KAMINUMA and CHIBA, 1973), it is located at 69°00′31.7″S, 39°35′31.6″E, 20 m above mean sea level. The seismic signals are transmitted over the distance of about 600 m by analog cables to the Earth Science Laboratory, where the acquisition system has been operating.

STS is a seismometer with broad-band frequency range, wide dynamic-range of about 140 dB and high sensitivity of 2400 Vs/m (WIELANDT and STRECKEISEN, 1982; WIELANDT and STEIM, 1986). The STS has two different seismic signals, broad-band (BRB) velocity output and long-period (LP) acceleration output. BRB output produces a flat frequency response for velocity from 0.1 s to 20 s in the 20-s mode and from 0.1 s to 360 s in the 360-s mode, respectively. In contrast, the LP output has a flat response to acceleration for periods longer than 20 s, or 360 s for each recording mode. There is an another output in STS for the monitoring of the boom position of the sensor (POS) that produces an analog output proportional to the offset of the pendulum from the null position (STRECKEISEN and

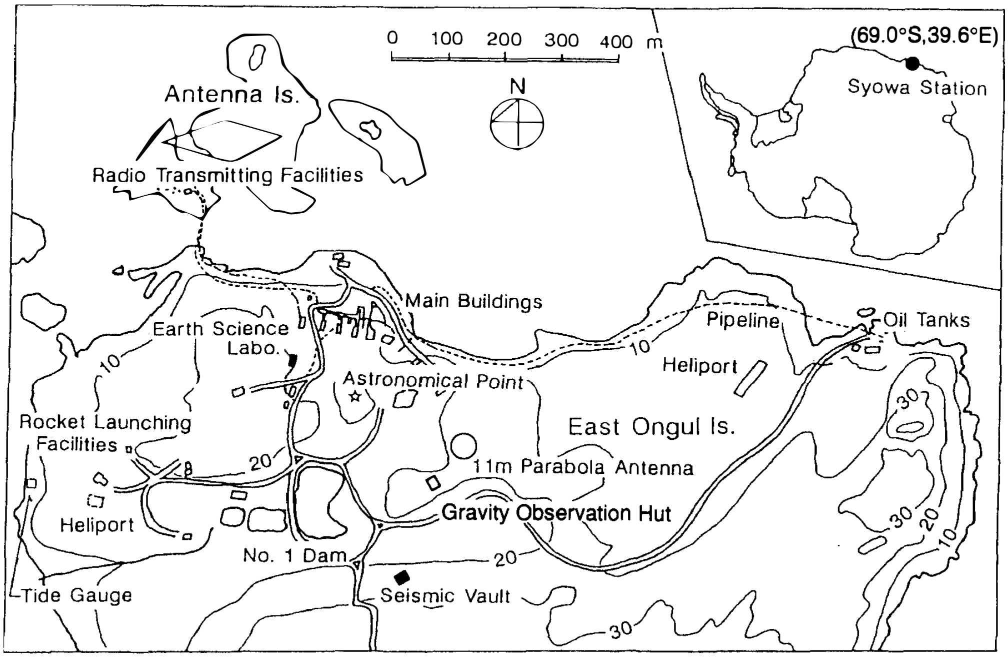

Fig. 2. Map showing the location of facilities for geophysical observations at Syowa Station. Contour interval is 10 m.

MESSEGERAETE, 1987).

The block diagram of the STS acquisition system at Syowa Station is illustrated in Fig. 3. The upper part shows the BRB recording system; the lower part shows the LP and POS recording systems, respectively. The details of the data acquisition of each signal are described below.

2.1. *BRB velocity signal*

The BRB recording system consists of a long-term thermal pen recorder with a chart speed of 2 mm/s (analog monitor in Fig. 3) and a digital recording system making use of an analog-to-digital converter, personal computer and hard-disk. The BRB signal, after being passed through an anti-aliasing analog low-pass-filter with the cut-off frequency of 2.80 Hz, is digitized at the sampling frequency of 20 Hz by an analog-to-digital converter (digitizer in Fig. 3) with a dynamic-range of 140 dB (about 24 bits).

Next, the digitized signal is transmitted to a personal computer through an RS-232C interface, then resampled as 10 Hz data by making use of acquisition software on the MS-DOS operating system. These continuous data are stored on hard disks, to be transmitted to magnetic tape of capacity 20 Mbytes (Mb) every 2 days. There is also an off-line system, consisting of a personal computer and hard disk, in order to edit the events and to re-sample from the original 10 Hz data into 1 Hz in the Earth Science Laboratory. This operating procedure has been carried out by the wintering members of the geophysical division of JARE.

The capacity of 10 Hz data of each day amounted to about 15 Mb, compared to about 1.5 Mb for the 1 Hz resampled data. Some large earthquake events are copied onto the 1.2 Mb floppy diskettes as 10 Hz data. The data format with the observation periods of

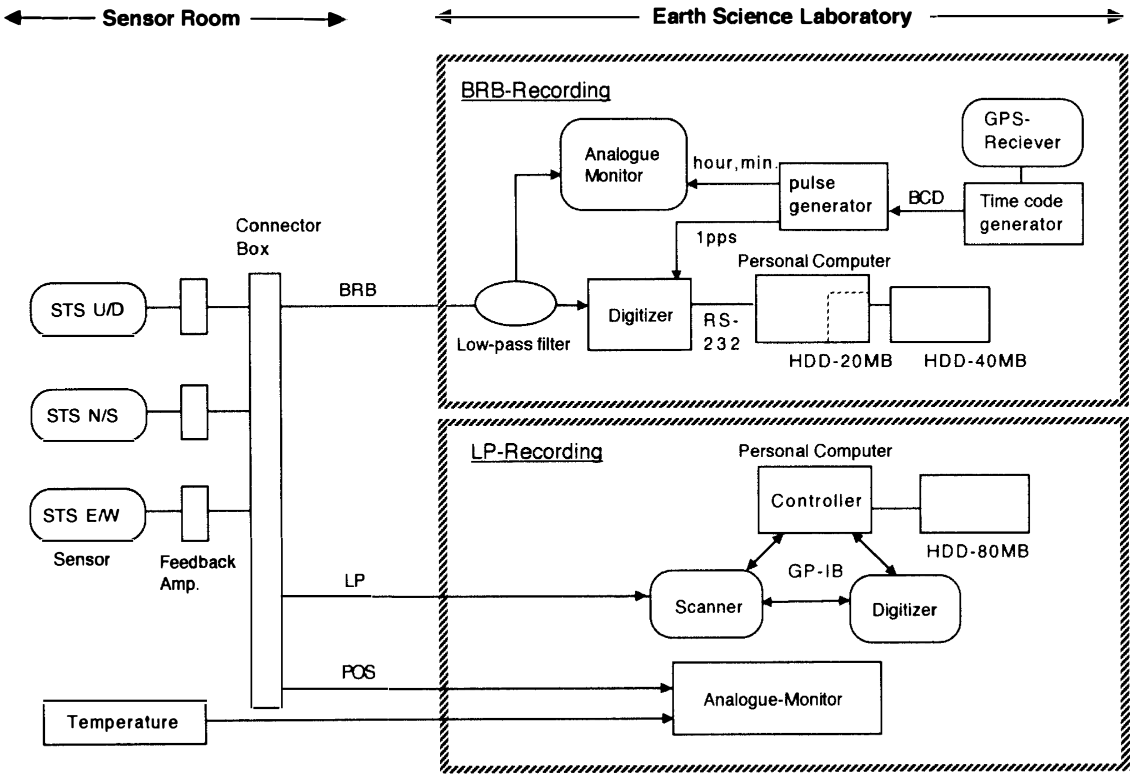

Fig. 3. Block diagram of STS recording system at Syowa Station. Upper figure : BRB-recording system ; Lower figure : LP-recording system.

Table 1. Data formating and the observation periods of digital acquisition system of BRB and LP outputs of STS-seismograph at Syowa Station, East Antarctica.

Observation period	Data kind	Sampling frequency	AD resolution	Recording media	
1) BRB output					
May 1990-Jan. 1993	Continuous data	1 Hz	24 bit	Magnetic tape	(20 Mb)
	Earthquake events	10 Hz	24 bit	Floppy diskette	(1.2 Mb)
Feb. 1993-	Continuous data	20 Hz	24 bit	MO distte	(600 Mb)
2) LP output					
Feb. 1992-	Continuous data	3.0 s	20 bit	Magnetic tape	(80 Mb)

the digital acquisition system is presented in Table 1. The data recording media was changed to 600 Mb magnet-optical (MO) diskette from February 1993 at the sampling frequency of 20 Hz. Information on the seismic observations at Syowa Station and the seismic data is available from the authors.

This digital recording system started BRB output in May 1990 (NAGASAKA *et al.*, 1992). In the wintering season of JARE-33 from February 1992 to January 1993, the current operating system of analog monitoring and the digital recording system were maintained. During this period, observation modes for the three-component BRB output were mainly carried out in the 20-s mode for the vertical component, and in the 360-s mode for the two horizontal components, because characteristic noises in the 360-s mode have been recognized in the vertical component.

2.2. LP acceleration signal

The digital acquisition system of the LP channel consists of a scanner (multi-plexa), digitizer, personal computer and hard disk. The LP signal is directly scanned (without an anti-aliasing analog filter) in turn among three components and digitized at a sampling period of 3 s by an analog-to-digital converter with a dynamic-range of 20 bits, to be transmitted and stored in the 80 Mb hard disk. These processes are controlled by the acquisition software on the MS-DOS operating system through a GP-IB interface (IEEE-488).

The stored data are transmitted to a magnetic cassette tape of capacity 80 Mb every month. This acquisition system is the same as that used for the superconducting gravimeter which has been operated from March 1993 at Syowa Station (SATO *et al*., 1993). The data capacity in one day is about 1 Mb. The digital acquisition system for LP output started in February 1992 at the beginning of JARE-33 wintering operation. Data formatting and observation periods of the digital acquisition system of BRB and LP signals are presented in Table 1.

2.3. POS position signal

The three-component output of the STS boom position is also monitored by an analog recorder with chart speed of 20 mm/hour. The adjuster electronics for null position has made it possible to control the position remotely from the Earth Science Laboratory since 1990. The temperature inside the thermal sealed box of the vertical component sensor is also monitored in order to investigate the relationship between the pendulum position drift and the temperature variation. The strong influence of the temperature change on the boom position has already been pointed out since the STS-seismograph was installed (MURAKAMI and KAMINUMA, 1991; NAGASAKA *et al*., 1992; YAMAMOTO, 1993; KANAO and KAMINUMA, 1993).

In the wintering season of JARE-33, moreover, the installation condition of the sensor was improved in order to investigate the quantity of the drift rates of the boom position and the characteristic noises. They were investigated by comparing two vertical sensors under different installation conditions, such as different methods of fixing the glass plate to the concrete platform in the seismographic room by use of plastic clay and cement. Details of the arrangement of the instruments in the wintering season of JARE-33 are described by KANAO and KAMINUMA (1993).

2.4. System clock

The STS system reference clock has been connected to the UTC recovered from the NNSS (Navy Navigation Satellite System) since February 1987. A test measurement of receiving UTC by GPS (Global Positioning System) satellites instead of NNSS was conducted during the wintering period of JARE-33. An illustration of how the reference timing pulse was obtained from the GPS-receiver is presented in Fig. 3. It is planned to change the system clock from NNSS to GPS at the Earth Science Laboratory.

2.5. Data transmission

Test transmission of the digital data (BRB and LP) to the National Institute of Polar Research from Syowa Station has been successfully continued via the satellite telecommunication system. It is available for the other researchers to obtain the digital seismic records of STS in quasi real-time upon the request by making use of this satellite system.

3. Examples of Waveform Records

The onsets of the earthquake events were detected on the short-period (HES) and long-period (PELS and STS) seismograms from the thermal-pen analog monitor records. Most of the phases were scaled on the vertical component, and only clear phases were indicated on the horizontal components. The teleseismic events were recognized by comparing the travel time of the initial phases with that of the events listed in the Preliminary Determination of Epicenters (PDE) by the National Earthquake Information Center (NEIC). Some phases were identified clearly, particularly in the STS seismograph, comparing to the other records of seismometers (HES and PELS).

The hypocentral distribution of earthquakes whose waveforms are recognized at Syowa Station in 1992 is plotted in Fig. 4. The number of the recorded events in a year

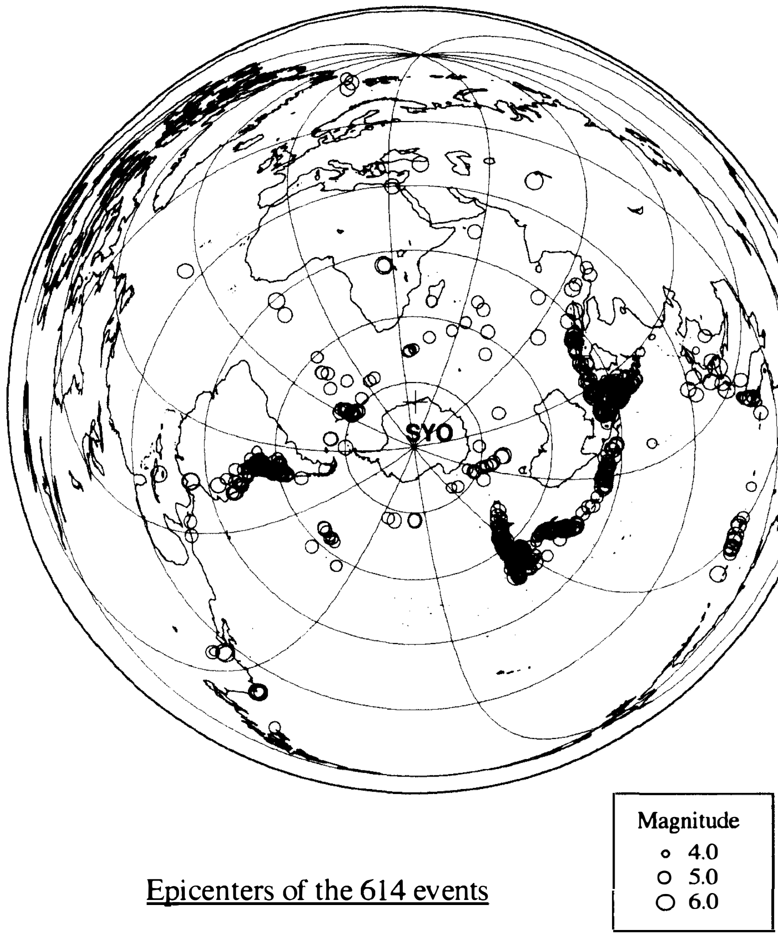

Fig. 4. Distribution of the location of earthquakes whose initial phases were detected by the seismic recording system at Syowa Station from January to December, 1992. The total number of events is 614. The plotted hypocenters are referred to Preliminary Determination of Epicenters (PDE) by NEIS. The radius of each circle is proportional to the degree of Magnitude.

during this observation period is 614. The location of Syowa Station is taken to be the center of this equidistant, azimuthal global-map. The number of the recorded earthquakes will certainly be increased when considering more local, small events around the Antarctic region. The list of all events detected at Syowa Station since the installation of STS (1989) are presented in four years of JARE Data Reports, Seismological Bulletin of Syowa Station, Antarctica (KAMINUMA and MURAKAMI, 1991 ; KAMINUMA and NAGASAKA, 1992 ; KAMINUMA and YAMAMOTO, 1993 ; KANAO, 1994).

3.1. BRB seismograms

Some examples of digital seismograms with a three-component BRB signal are shown in Figs. 5a–5d. Figures 5a and 5b show examples of shallow teleseismic events ; Figs. 5c and 5d correspond to deep events.

Figure 5a shows the waveform for a shallow event near the coast of Nicaragua. Observation modes are the 20-s mode for the vertical component and the 360-s mode for the horizontal components. Figure 5b is an event in the Kermadec Islands Region. The observation mode is the same as in Fig. 5a. The predominant core phases (SKS, SKKS, S'S'(=SKSSKS), PKiKP, P'P'(=PKPPKP), etc.) and converted phases (PS, SKKP, PKKS, etc.) are detected. Inhomogeneity and anisotropy of the core and the mantle can be studied by analyzing the characteristics of waveform propagation such as attenuation and by analyzing the shear wave splitting from the particle motion for these phases. The surface waves (Love and Rayleigh waves) are recognized on these seismograms in addition to several phases of body waves. The regional difference of the lithosphere structure will be determined by making use of these waveforms in the dispersion analysis (following the result of ROULAND and ROULT, 1992).

Figures 5c and 5d are examples of deep events in the Fiji Islands Region and Vanuatu Islands, respectively. In addition to core phases and converted phases of body waves, core reflections (ScS, etc.) from the Core-Mantle boundary (CMB) can be recognized. The principal depth phases (pP, sS, etc.) associated with the body waves are also detected. Structural heterogeneity of Mantle, CMB and the source area of the events will be clarified by analyzing these phases.

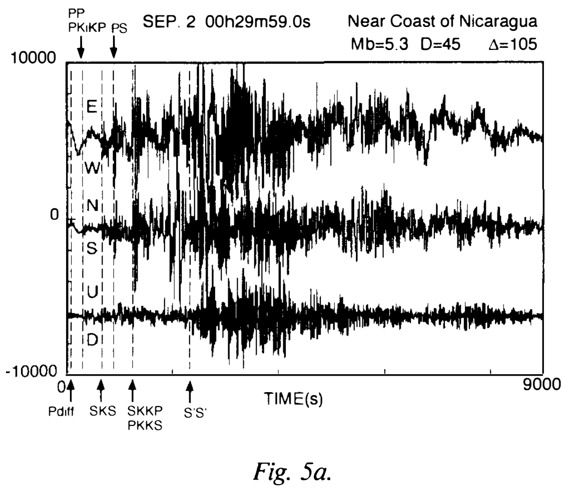

Fig. 5a.

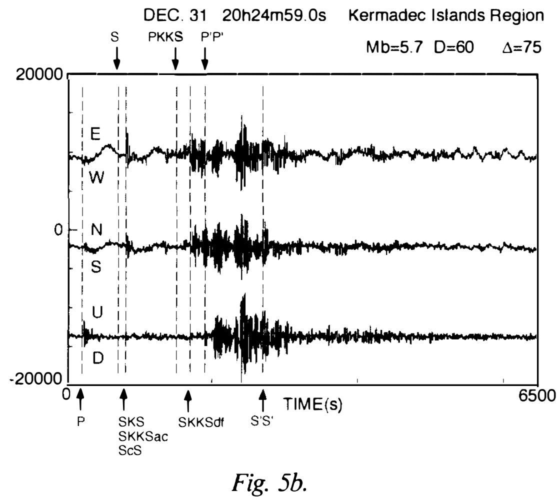

Fig. 5b.

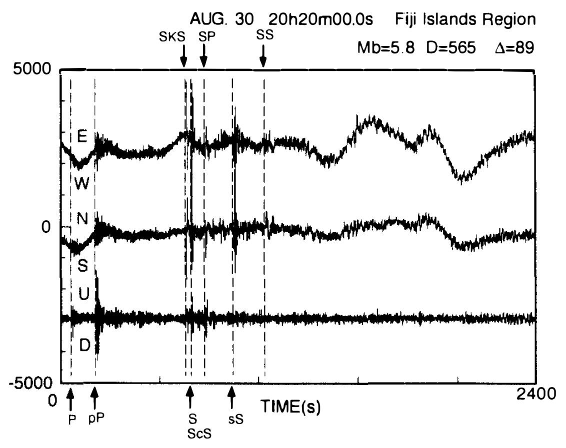

Fig. 5c.

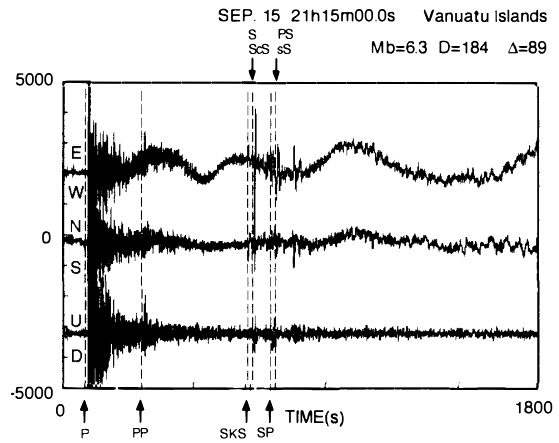

Fig. 5d.

Figs. 5a–5d. Digital seismograms of BRB (broad-band) velocity output for the three-component STS seismograph 20-s mode for vertical component and 360-s mode for horizontal components. The sampling frequency is 10 Hz. Hypocenter parameters of the earthquake are as follows :

(a) Origin time, 0016:01.6, September 2, 1992 ; location, 11.742°N, 87.340°W ; depth, 45 km ; Mb = 5.3, Ms = 7.0, near coast of Nicaragua.

(b) Origin time, 2017:08.6, December 31, 1992 ; location, 32.015°S, 178.025°W ; depth, 16 km ; Mb = 5.8, Kermadec Islands region.

(c) Origin time, 2009:05.7, August 30, 1992 ; location, 17.918°S, 178.710°W ; depth, 565 km ; Mb = 5.8, Fiji Islands region.

(d) Origin time, 2103:59.9, September 15, 1992 ; location, 14.053°S, 167.269°E ; depth, 184 km ; Mb = 6.3, Vanuatu Islands.

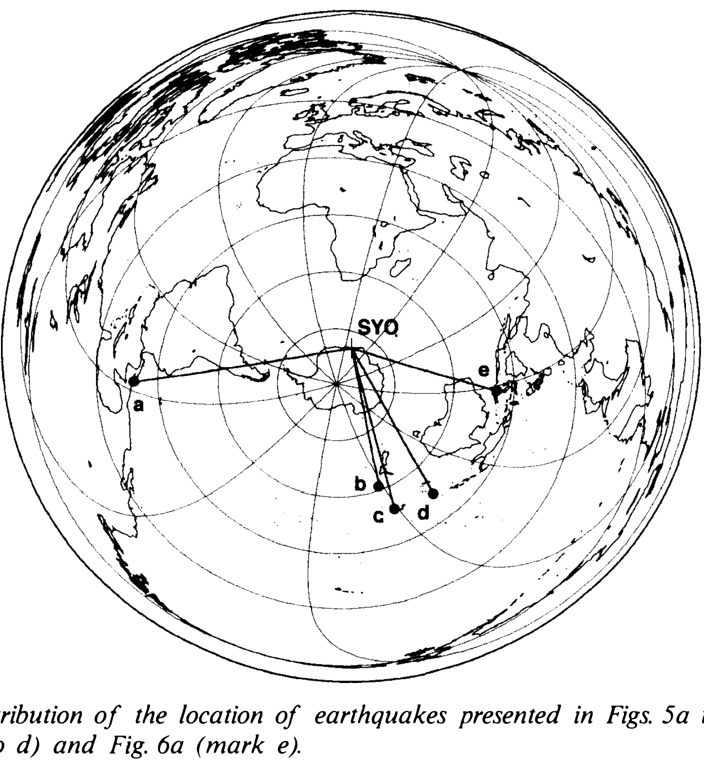

Fig. 5e. Distribution of the location of earthquakes presented in Figs. 5a to 5d (marks a to d) and Fig. 6a (mark e).

Figure 5e shows the distribution of the location of earthquakes presented in Figs. 5a–5d. The hypocenter of each event is connected to Syowa Station with a thick line, which indicates the great circle path. It is expected that the interior of the Earth will be clarified, particularly in the southern hemisphere around the Antarctic region, by making use of the travel-time data and seismic waveforms of the high quality STS digital data at Syowa Station.

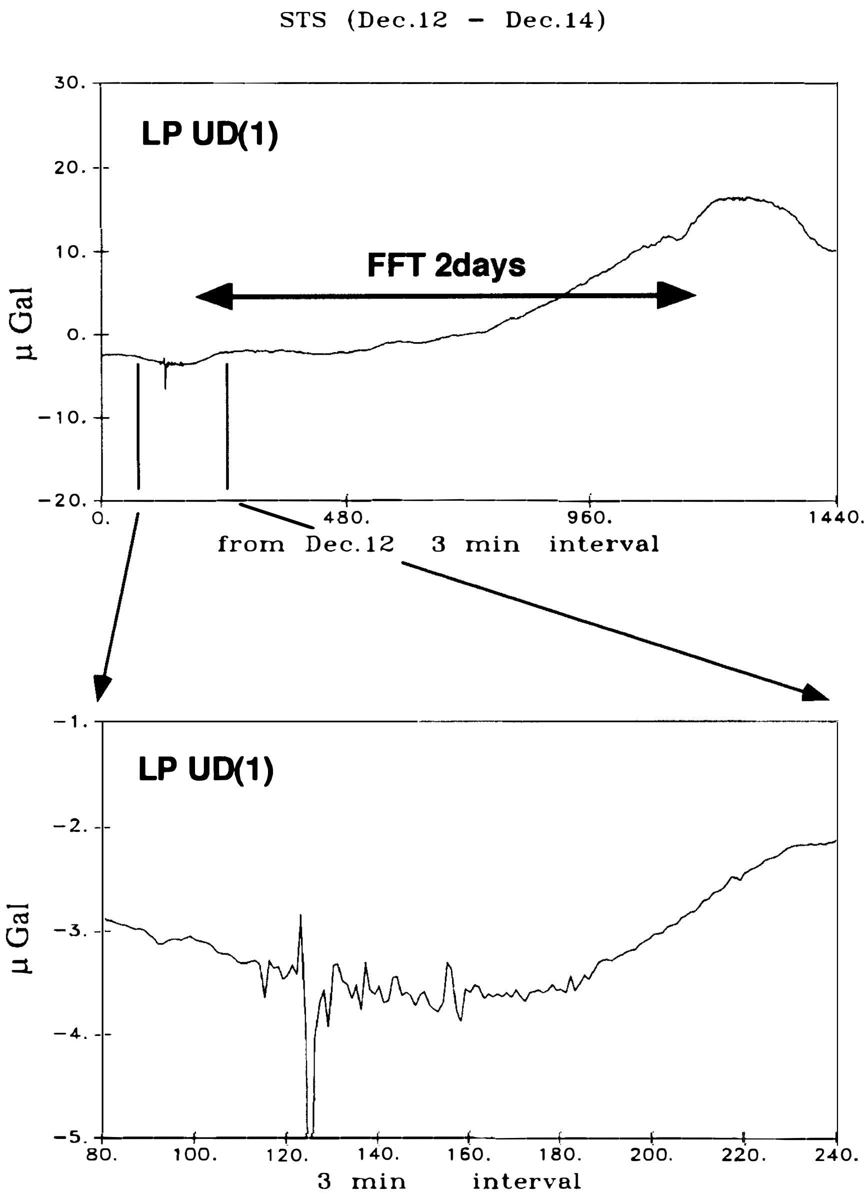

Fig. 6a. Digital seismogram of LP (long-period) acceleration output for the vertical component of STS seismograph (20-s mode). The sampling frequency is 2 s. Hypocenter parameters of the earthquake are as follows : origin time, 0529:27.4, December 12, 1992 ; location, 8.512°S, 121.891°E ; depth, 35 km ; Mb = 6.7, Ms = 7.5, Flores region, Indonesia.

3.2. LP seismograms

In this section, the possibility of analysis of LP data is considered in the frequency range around a few hundred seconds in the geodetic sense. Dynamic levels and dynamic ranges of seismometers and gravimeters by major global networks at the frequency representative of the Earth's free oscillations are presented by AGNEW *et al.* (1986). The possibility to carry out that analysis would be considerable by making use of the LP data for the single normal mode of free oscillation of the Earth as it is obtained from the data of the International Deployment of Accelerometers (IDA) network with a LaCoste & Romberg gravimeter and the MODE signals of the superconducting gravimeter (CUMMINS *et al.*, 1991). Some advantages of working with long-period digital data are considerable, that is, 1) describe accurate long-period source mechanisms, 2) estimate the attenuation for the modes of free oscillaiton, 3) investigate the aspherical Earth structure.

An observation by pendulum-type tiltmeter with STS-1 seismometer has been carried out on the Izu peninsula, Japan, in order to detect earthquake events and Earth tide signals (OKADA and ISHIDA, 1993). From the analysis, it has been confirmed that the waveforms are almost identical in both instruments, particularly in the vertical component.

Figure 6a shows the seismogram of the LP acceleration output for the vertical component of the STS-seismograph (20-s mode). This event occurred near Flores Island, Indonesia (event(e) in Fig. 5e). It recorded the maximum amplitude during the observation period of JARE-33 at Syowa Station. Figure 6b shows the Fourier spectrum amplitude of the record shown in Fig. 6a for 2 days from 4.5 hours after the occurrence of the event. Several normal modes of free oscillation of the Earth are identified. Theoretical periods of fundamental Spheroidal modes are illustrated by a group of short bars (SAILOR and DZIEWONSKI, 1978; MASTERS and GILBERT, 1983). The noise revel at period

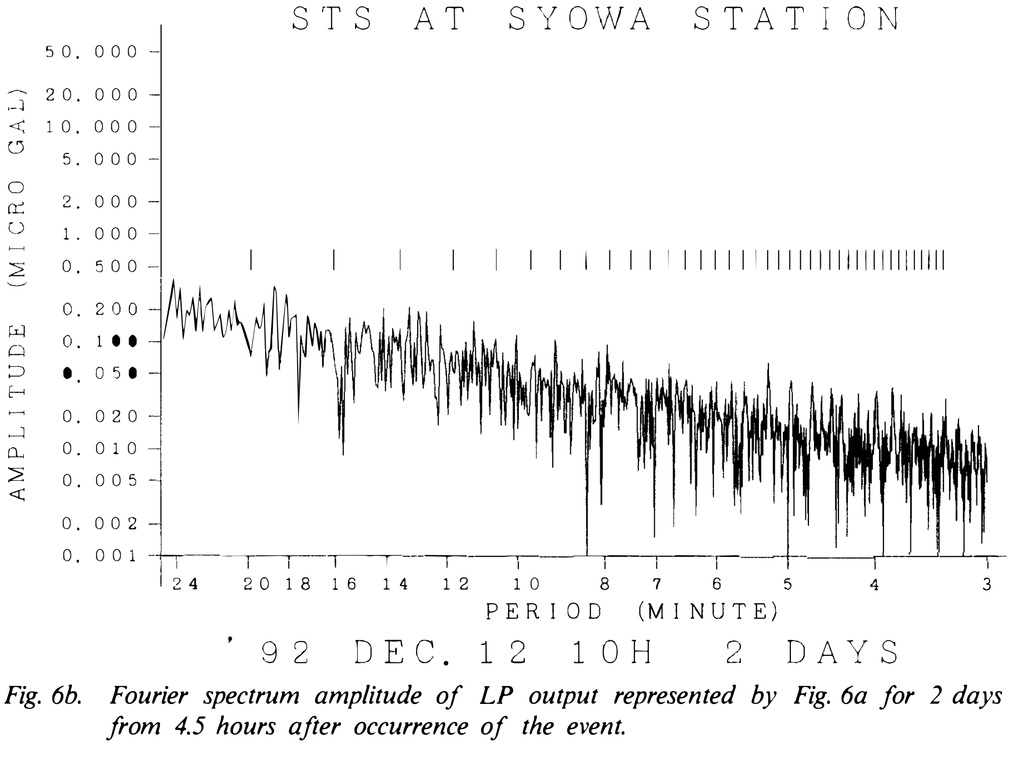

Fig. 6b. Fourier spectrum amplitude of LP output represented by Fig. 6a for 2 days from 4.5 hours after occurrence of the event.

longer than 500 s is rather high compared to the spectrum of the LaCoste & Romberg gravity meter (KANAO and SATO, 1993). This is considered to be caused by the recording limit of the STS-seismograph for a long period and by fluctuation of the meteorological effect.

It is hoped that enough quality data will be obtained for analysis of free oscillations of the Earth by comparing to the data of the superconducting gravity meter which has been operating at Syowa Station since March 1993 (SATO *et al.*, 1993).

4. Summary

Seismic observations with an STS-seismograph were made during the winter period of the 33rd Japanese Antarctic Research Expedition in 1992. The current observation system, hypocentral distribution of the detected events and some examples of recorded digital waveforms are introduced in this paper.

It is expected that the interior structure of the Earth, inhomogeneity and anisotropy of the core and the mantle, source mechanism of the large earthquakes, etc. to be revealed in the near future by making use of the travel-time or waveform data of the STS seismograph.

The seismic observations at Syowa Station are organized by the authors and K. SHIBUYA of the National Institute of Polar Research. Information on the seismic observations is available from them.

Acknowledgments

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