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A note on upgrading long-period seismographs

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RESUMEN

La utilidad de la señal generada por sismómetros electromagnéticos de periodo largo se puede incrementar convirtiendo esta señal a formato digital mediante el uso de componentes electrónicos de costo reducido. Con este propósito desarrollamos dos circuitos electrónicos. El primero para calibrar una estación de periodo largo de tres componentes (perteneciente a la Red Sísmica del Noroeste de México) y el segundo para digitalizar la señal generada por esta estación. La señal digital se suministra a continuación a una computadora personal (PC). En ella la señal entrante se decodifica, visualiza, graba y revisa mediante programas escritos para tal fin. La curva de respuesta en frecuencia de nuestra estación es similar a la de las curvas de las estaciones de periodo largo de la red World Wide Standardized Seismograph Network (para un periodo natural de 15 s). Como resultado del trabajo realizado se han obtenido registros digitales de periodo largo de buena calidad desde noviembre de 1996.

PALABRAS CLAVE: Sismógrafos, calibración, señal de periodo largo, digitalizar.

ABSTRACT

Signals generated by old-fashioned electromagnetic long-period seismometers can be digitized using low-cost electronics. We developed electronic hardware, including a calibration section, to digitize signals of a three-component long-period station. Software to decode and monitor the incoming signals on a PC was developed. The frequency response curve obtained is similar to curves of long-period stations of the World Wide Standardized Seismograph Network for a natural period of 15 s. Good quality digital long-period data have been obtained since November 1996.

KEY WORDS: Seismographs, calibration, long-period waveforms, digitize.

INTRODUCTION

Long-period data produced by old-fashioned seismographs are still useful in seismological research. Shearer (1991) used this type of data in a stacking procedure to study upper mantle discontinuities from converted and reflected seismic phases. Old-fashioned instrumentation is being displaced because of limited frequency band, lack of digital recording, and the advent of advanced seismic instrumentation; nevertheless the cost of modern instrumentation is high. We have provided an in-house design of a long-period digital acquisition system to supplement short period data in the Red Sísmica del Noroeste de México (RESNOM). A description of RESNOM can be found in Vidal and Munguía (1993) and Hinojosa Corona (1988).

We describe the calibration and digitization procedures for a long-period station. Some results derived from this work are a growing long-period database and the capability to extract basic information from the recorded teleseismic earthquakes. An additional benefit of the digital long-period data is for educational purposes.

INSTRUMENTATION

The long-period station (CCX, 31°52.1'N, 116°39.8'W) consist of three long-period seismometers with amplifiers, filters, analog drum recorders, and a digitization interface built in the present work. Figure 1 shows the seismometers, which are GEOTECH models 7505 (vertical) and 8700 (horizontal). The output of these seismometers is proportional to ground velocity. According to the manufacturer, the natural period can be adjusted from 10 to 30 seconds. The output signal is sent to amplifiers (200 k) and filters (2-pole low-pass, fc = 0.011 Hz), designed at the University of Nevada at Reno. The long-period signal is recorded on Sprengnether model VR-65 drum recorders. The CCX long-period station operates continuously since 1993 in the analog mode. We calibrated the system in November 1993, and we proceeded to digitize the analog signal. The first digital records from a M_s 7.0 earthquake in Peru were obtained on November 4, 1996.

CALIBRATION

Following the tests suggested by the manufacturer, for each seismometer we determined natural period, damping coefficient, and effective motor constant of the calibration coil. Natural period T_n was determined by measuring the time needed for the inertial mass to oscillate through one complete cycle. We measured at least five complete cycles, and took the average value. The damping coefficient λ was obtained from the overshoot ratio

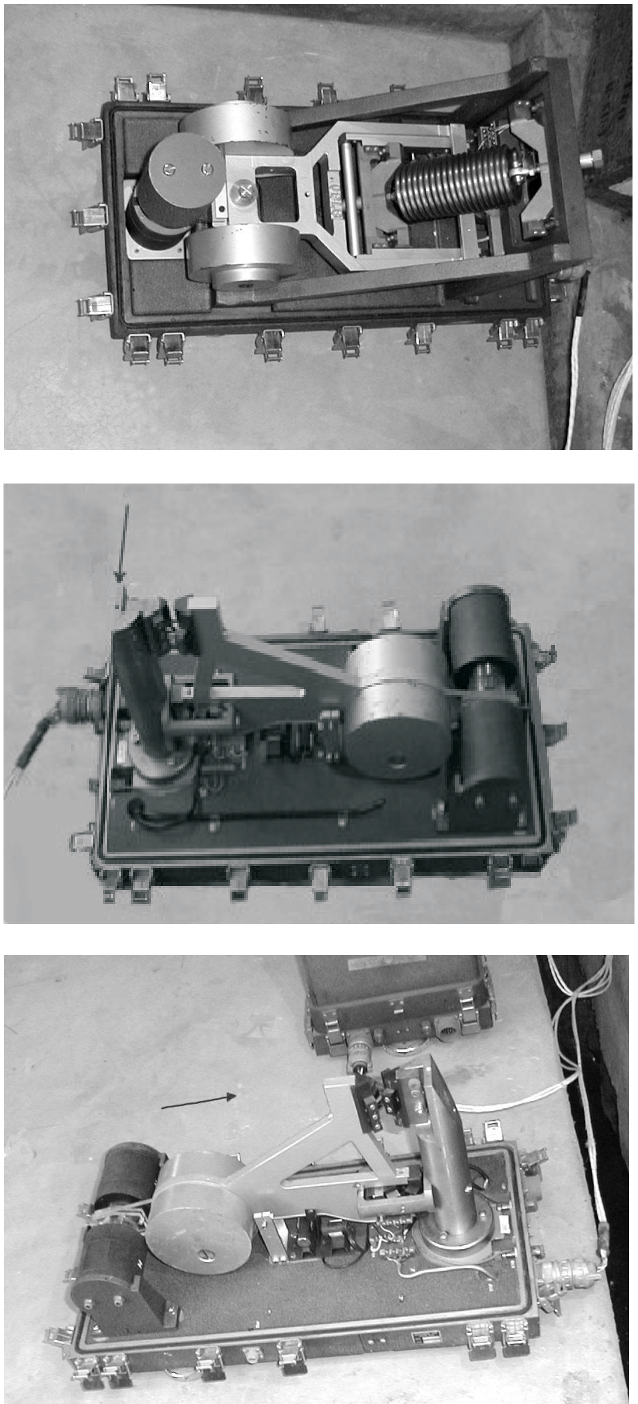

Fig. 1. GEOTECH long-period seismometers: model 7505 (vertical, upper), and models 8700 (N-S, middle; E-W, lower). In the middle and lower pictures, arrow pointing through the connector of the N-S instrument indicates the north direction.

measured on the step response of each seismometer. The effective motor constant *emc* of the calibration coil is derived from the equation:

$$emc = \frac{(980 \ x \ 10^{-5}) \ W(X_i \,/\, X_W)}{i} \ , \qquad (1)$$

where W is a small weight on the suspension arm of the seismometer, X_W is the deflection of the seismometer due to the weight lift, X_i is the deflection of the seismometer caused by turning off the current i applied to the calibration coil. The calibration results are summarized in Table 1.

Next, we designed an electronic circuit that generates a calibration signal to test the whole instrumentation (seismometers, amplifiers, filters, and recorders). A voltage step of 5 V was applied to the seismometer calibration coils, and maintained during 3 minutes to allow the seismometer masses to swing and reach their initial position. As the voltage drops to zero the masses swing in the opposite direction and return to their initial position. Correct operation of the equipment may be ascertained by a visual inspection of the step response of the station. Figure 2a shows plots of the response per component to the voltage step applied.

Frequency response. Considering the station as a linear system, the empirical Fourier velocity frequency response H(ω) is

$$H(\omega) = \frac{O(\omega)}{I(\omega)} \frac{\omega \, R \, m}{emc} \ , \qquad (2)$$

where O(ω) and I(ω) are the spectra of the output (step response) and input (voltage step), respectively; ω is the angular frequency, R is an external resistance of 4750 Ω through which the calibration signal is applied, and m is the mass of the seismometer (10 kg). The amplitude spectra of a step function is ω^{-1} (Bracewell, 1965), thus the spectra of our input signal is $I(\omega) = E/\omega$ where E is the amplitude of the voltage step. Substituting this relation in Equation (2) we get

$$H(\omega) = \frac{O(\omega)}{E} \frac{\omega^3 \, R \, m}{emc} . \qquad (3)$$

This equation was used to compute the displacement frequency response curves shown in Figure 2b. From these curves we see that the maximum peak occurs at around 10 seconds, which is close to the natural period obtained from the initial calibration tests. The shape of the amplitude curve for each component is similar to that of the long-period stations of the World Wide Standardized Seismograph Network. The amplitude response curve is valid from around 5 to 25 seconds.

From the calibration results and the experience acquired

Table 1

Values found in the initial calibration tests done on seismometers. See text for details.

Seismometer	Serial number	Component	i ($x10^{-3}$A)	X_i ($x10^{-3}$ V)	W (g)	X_W ($x10^{-3}$ V)	emc (N/A)	T_n (s)	λ
7505 A	79	V	59.34	10	0.2	10	0.033	10	0.6
8700 C	130	N-S	42.19	9	0.1	10	0.021	9	0.6
8700 C	128	E-W	29.28	9	0.1	10	0.030	9	0.6

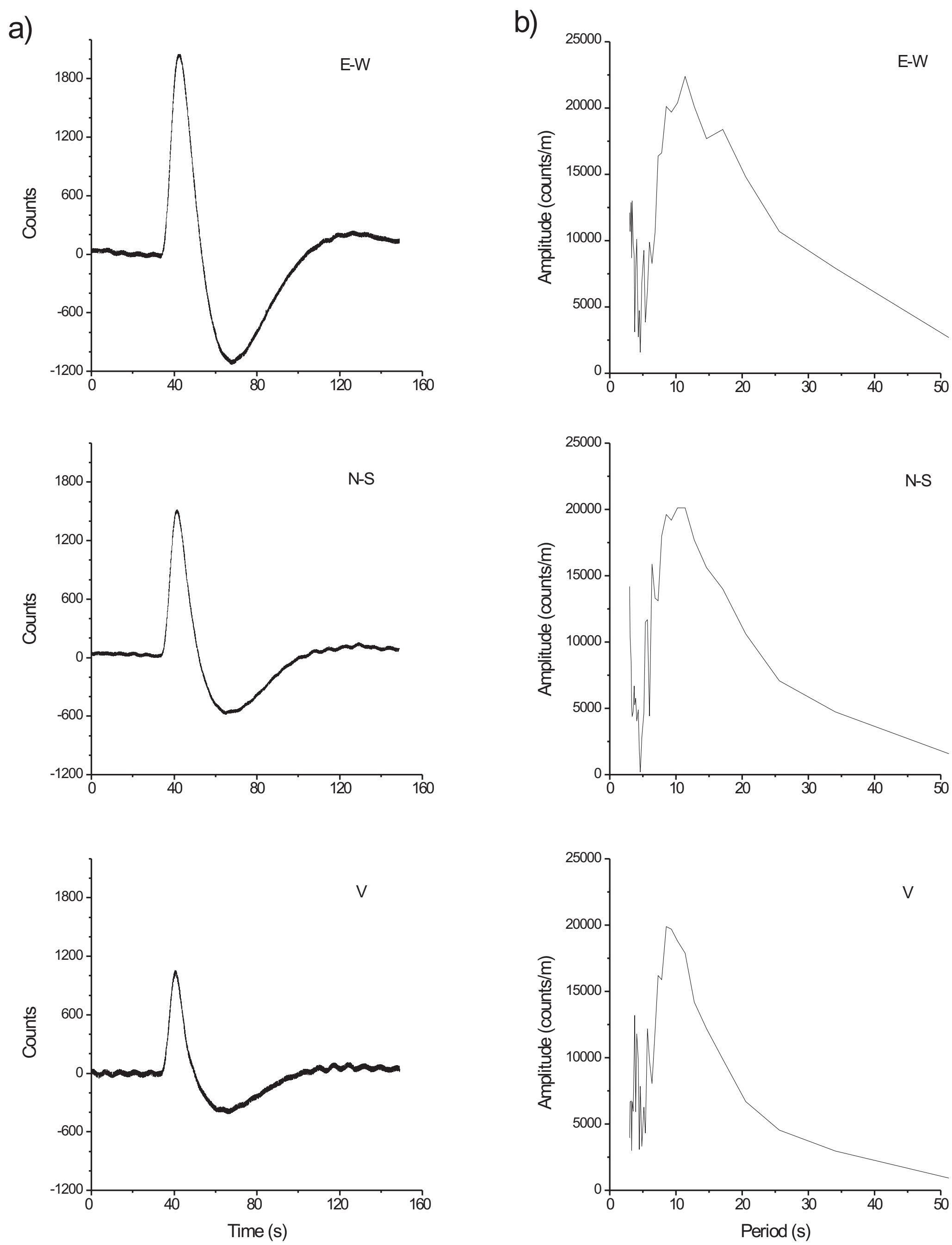

Fig. 2. (a) Step response and (b) displacement frequency response of the CCX long-period station.

since 1993, we increased the natural period of seismometers up to 15 s and reduced the gain of amplifiers from 200k to 100k. From these changes we were able to obtain on-scale records from central-Mexico earthquakes of $M_s \sim 6.5$.

DIGITIZATION

The signal produced by the seismometers is amplified (100 k) and filtered (fc = 0.011 Hz) before digitization. Figure 3 shows a block diagram of the stages in the digitization procedure. A regulated power supply provides ±12 V to the electronic components of all sections. The control section produces the signals that allow synchronize the other sections. The multiplexing section selects each component to be digitized. The sample-and-hold stage takes a sample of the selected component and holds it to convert it to digital form. A 12-bit A/D successive approximation converter provides one sample per second (sps) per component. These data are formated by the addition of four bits. Two bits are used to identify the first and the second bytes that characterize a sample of data. The remaining two bits allow identification of the component (Figure 4). The serializing stage converts data from parallel to serial form. Finally, this serial signal is converted to an RS-232 interface standard that is compatible with digital radio links or PC communication ports.

Because of the sampling rate of 1 sps, the Nyquist period is 2 seconds. At this period the magnification of the station is low (Figure 2b), implying that the aliasing effect is not present in the digital signals obtained. The dynamic range of these signals is 72 dB, which allows on-scale records with amplitudes within ~3.5 orders of magnitude.

SOFTWARE DEVELOPED

From November 1996 to February 2001 our recording system was based on the MS-DOS operating system, and the computer was dedicated to record the incoming signal. To analyze the recorded data, we interrupted the recording process to transfer the data to another computer. At present the recording system uses the LINUX operating system, with the advantage of multitask capability, feasibility of working in real time, use of windows environment, and Internet connectivity.

To check and decode the incoming signal, we wrote a program in C language. The program obtains each component separately and includes every minute the Universal Time Coordinated. The time mark is synchronized with the time code provided by one of the two Geostationary Operational Environmental Satellites. Another program was designed to plot the decoded signal in real time. Raw data are recorded in binary files that contain 12 hours of continuous data. The seismic signal of interest is extracted based on a STA/LTA algorithm and then converted to SAC or SEISAN formats for further processing.

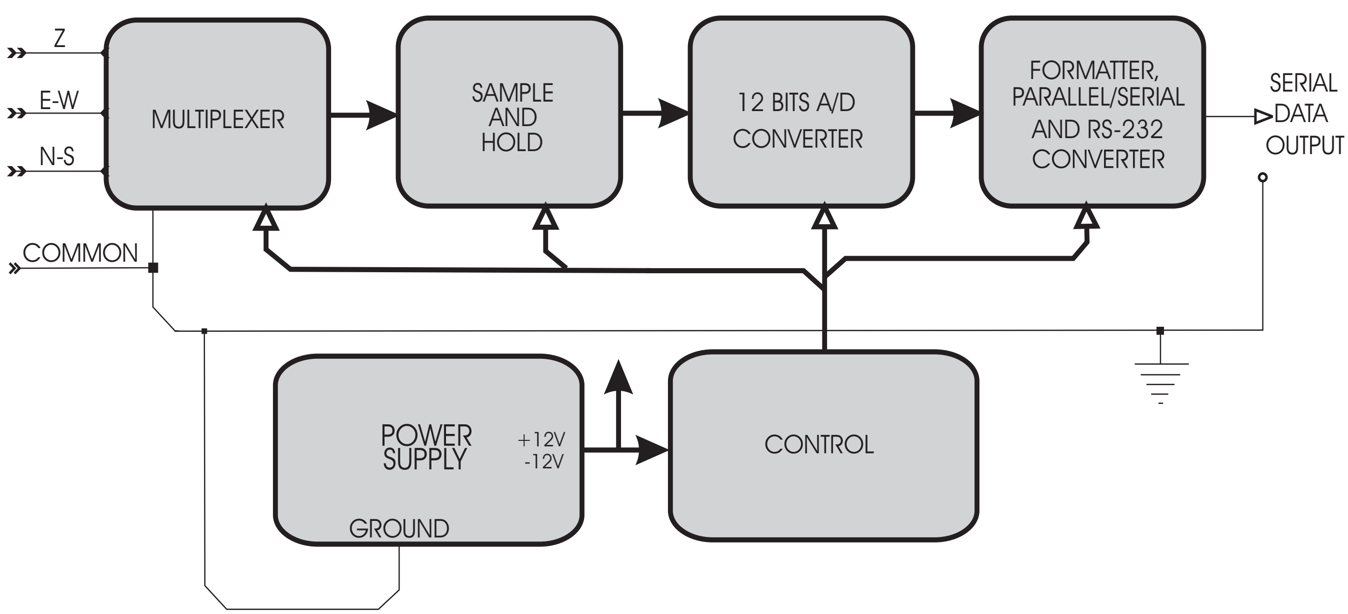

Fig. 3. Block diagram of the stages in the digitization procedure.

SOME SEISMOLOGICAL RESULTS

A long-period database is being constructed as proposed in the SEISAN program (Havskov and Ottemöller, 1999). This is consistent with the short-period and broadband database of the RESNOM network. Figure 5a shows an example of the original long-period digital records for a M_s 6.9 earthquake occurred on 20 September 1997 in the Kermadec islands region. Some seismic phases in the seismograms were interpreted using the Jeffreys - Bullen travel-time curves. Note the Gutenberg (G) wave, and the classical Rayleigh (R) waves traveling across an oceanic path. We converted these seismograms to SAC format in order to increase the possibility of a deeper analysis (arrival times, spectra, filtering, rotation of components, among others) using the SAC general program (Goldstein *et al.*, 2001). An example is the rotation of the horizontal components shown in Figure 5a, to clarify the interpretation of the G wave (long-period Love wave). This wave is emphasized in the tangential component depicted in Figure 5b. Having data in SAC format permit their use with the SEISMIC WAVES program (Jones, 1994-1997) for educational purposes. This program illustrates the travel of seismic waves through the Earth's interior and their appearance on seismograms.

Figures 6a and 6b show plots of the magnitude of earthquakes recorded during the years 1993 and 1994, respectively. From these plots we observe that the lower-limit magnitude (dashed lines) for clear P and S arrivals at our station is around 4.5. This lower-limit magnitude corresponds to earthquakes recorded at distances of 300 to 750 km. Figure 6c shows a comparison between magnitudes at CCX station and those taken from the United States Geological Survey-National Earthquake Information Center (USGS-NEIC) bulletins. The observed differences may be due to a comparison of single magnitudes against average magnitudes reported by USGS-NEIC.

SUMMARY

We designed a low-cost digital recording system to gather long-period data generated by old-fashioned electromagnetic seismometers. This system has permitted the construction of a growing database since November 1996. We realize that the dynamic range of our system can be increased using D/A converters of 16 bit or more. These converters are available now at reasonable costs and will be used to improve our design.

The electronic hardware and software developed by us are available on request, and can be easily implemented.

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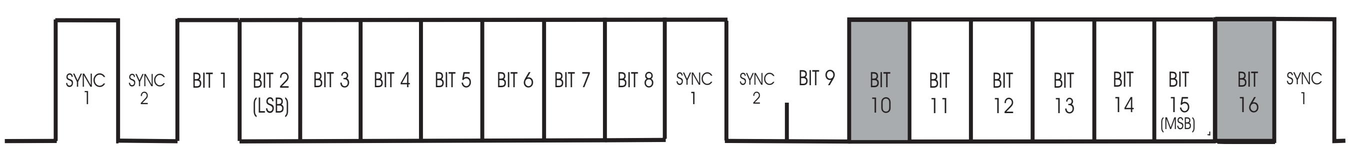

SYNC 1 AND SYNC 2 : Stop and start bits used in asynchronous digital transmission.

BIT 1 : It identifies the first byte of the sample. It is always high (positive).

BIT 2 TO BIT 8 : These are the least significant bits of the sample.

BIT 9 : This bit identifies the second byte of the sample. It is always zero (ground).

BIT 10 AND BITS 16 : Bits used to identify the type of component sent (Z [1 0], N-S [0 0], or E-W [0 1]).

BIT 11 TO BIT 15 : These are the most significant bits of the sample.

Fig. 4. Format used in digital asynchronous transmission of the long-period data.

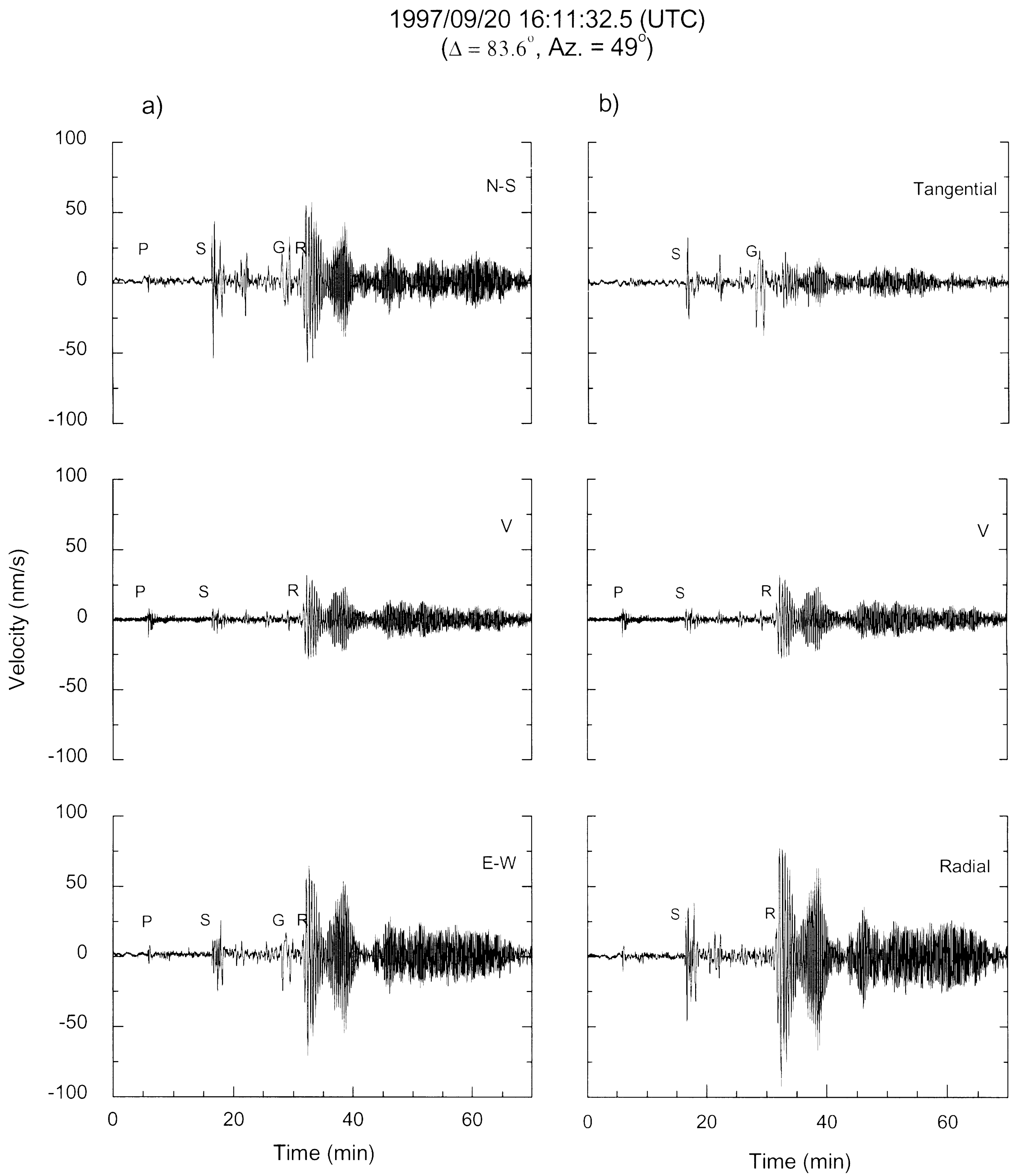

Fig. 5. Original (a) and rotated (b) seismograms of a M_s 6.9 earthquake of the Kermadec Islands region (lat. 28.683 S, long. 177.624 W, depth 33 km). Seismic wave amplitudes are 8 dB above the background noise level in the record.

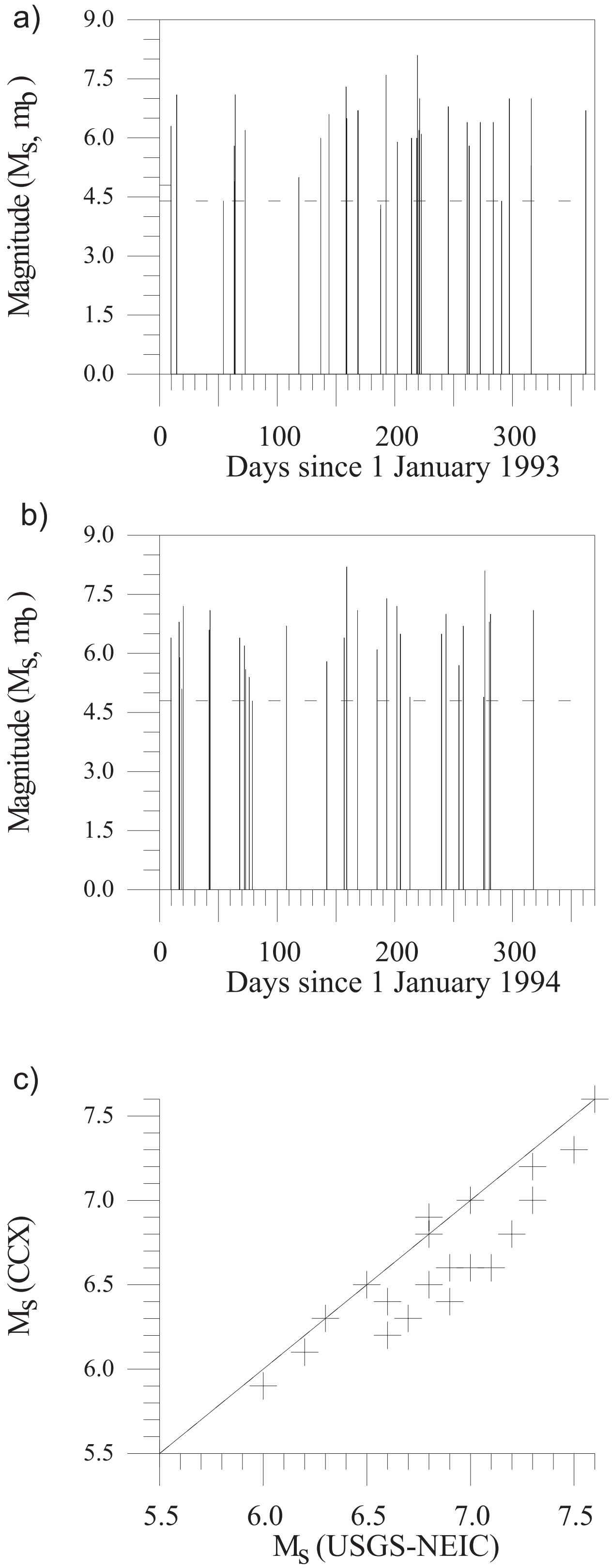

Fig. 6. Plots of magnitude of the earthquakes recorded by the CCX station during 1993 (a) and 1994 (b), and plot of M_s magnitudes reported by USGS-NEIC against those calculated from CCX data (c). The straight line in Fig. 6c represents equality between both magnitudes.

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