

## Exchange of digital seismological waveform data in Europe: status as illustrated by data collection for the 1992 Roermond earthquake, the Netherlands

Bernard Dost & Reinoud Sleeman

*ORFEUS Data Center, Section of Seismology, Royal Netherlands Meteorological Institute, P.O. Box 201, 3730 AE De Bilt, the Netherlands*

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### Abstract

The 1992 Roermond earthquake (location 51.16°N, 5.95°E;  $M_L = 5.8$ ) provides a good opportunity to evaluate the current status of exchange of digital waveform data in Europe. For this purpose data are collected from broad-band and short-period seismograph stations. It is the intention to publish these data on CD-ROM. The data set is evaluated on data quality, accessibility and spatial coverage of the recording stations. In order to compare signals from different stations attention has been given to the instrumentation. Evaluation shows that in contrast to broad-band networks, short-period networks in north-west Europe are not prepared for an event of this magnitude. It is recommended to increase the limited dynamic range of most digital stations and to evaluate the effectiveness of the currently used bandwidth. Finally, an organized common access to the data set, as is realized for the broad-band data, is recommended for regional, short-period networks.

### Introduction

In the past few years the number of worldwide deployed digital seismograph stations increased considerably. This trend can be seen in research-oriented broad-band stations as well as in short-period networks monitoring local seismicity and/or (nuclear) explosions. It is important that the digital waveform data are shared by the entire international research community. However, this can only be effective if a good organization of the data flow and standardization of the data archival format is realized. A general availability of software to handle files stored in the archival format is needed to ensure acceptance of the standard.

The ORFEUS Data Center (ODC) was initiated to organize the digital data flow for broad-band stations (Dost 1991). Data from European stations are collected, converted to a standard archival format and distributed to the users on CD-ROM. Moreover, the ODC recently realized on-line access to the data base through a 'gopher'-system that will be discussed in this paper. Although short-period regional networks in

Europe are prepared to cooperate and exchange data, a structure like the ODC is not yet available. Early 1993 the ODC changed hosting organization from the university of Utrecht to the Royal Netherlands Meteorological Institute (KNMI). The change ensured more stability in the long-term funding of the ODC. In addition, it brought the ODC in close contact with seismologists involved in the operation of a regional network and in international data exchange within the Group of Scientific Experts (GSE) of the conference on disarmament in Geneva and the 'transfrontier'-group.<sup>1</sup> This unique opportunity enabled us to evaluate procedures in use at different groups.

This paper discusses the present status of digital data exchange within Europe as illustrated by the 1992 Roermond event. In particular we focus on the exchange of digital waveform data and we recommend improvements. It is the intention to produce a CD-ROM with all collected data in the 'Standard for the Exchange of Earthquake Data (SEED)' format. The

<sup>1</sup> This group originated from an EC-funded program and is chaired by Chris Browitt (British Geological Survey, Edinburg, UK)

Table 1. List of networks and stations that contributed their data for the Roermond earthquake and are located within the European region, as defined by the European Seismological Commission (ESC)

Station/ Network name	Number of stations	Number of channels	Instrument type	Sampling rate (sps)
GEOSCOPE*	02	2*Z,N,E	STS-1, VBB	20
GRAEF	13	10*Z, 3*Z,N,E	STS-1, BB	20
GRSN	08	8*Z,N,E	STS-2, VBB	80
IRIS**	04	1*Z,N,E	STS-1, VBB	20
MedNet***	03	3*Z,N,E	STS-1, VBB	20
UKNET	14	12*Z, 2*Z,N,E	Mod. MK-3C, BB	10
PRU	01	1*Z,N,E	SKD, BB	27.78
PSZ	01	1*Z,N,E	STS-2, VBB	80
STU	01	1*Z,N,E	STS-1, VBB	20
UPP	01	1*Z,N,E	STS-1, BB	20
ECH	01	1*Z,N,E	STS-1, BB	5
ETH	01	1*Z,N,E	STS-1, VBB	20
KHC	01	1*Z,N,E	SKD, BB	31.25
NRA0	01	1*Z,N,E	KS-36000, BB	10
ARA0	01	1*Z,N,E	KS-36000, BB	10
GEC2	01	1*Z,N,E	BB-13, BB	10
NARS	13	13*Z,N,E	Mod. SL 210/220, BB	8
BGS	12	11*Z, 1*Z,N,E	MK-III, SP	100
LDG****	29	27*Z, 1*Z,N,E	SP	50
ORB	19	11*Z, 8*Z,N,E	div. e.g. L4, SM-6; SP	100–500
KNMI	11	11*Z	MK-III, SP	50
KARLSRUHE	24	11*Z, 13*Z,N,E	SP	150–200
GERESS	25	21*Z, 4*Z,N,E	GS-13, SP	40
NORESS	24	20*Z, 4*Z,N,E	GS-13, SP	40
ARCESS	24	20*Z, 4*Z,N,E	GS-13, SP	40
FINESS	16	16*Z	GS-13, SP	40

\* GEOSCOPE stations SSB, TAM; \*\* IRIS/IDA stations KIV, OBN; IRIS stations KONO, TOL (now PAB); KEV (DWWSSN): through IRIS DMC; \*\*\* MedNet stations AQU, BGY, BNI; \*\*\*\* LDG has 22 Z-components with high gain, 5 have added low-gain components. See Appendix for abbreviations.

data will be available to data contributors and interested scientists. The subject of this paper implies the use of many abbreviations. These are explained in the Appendix.

### Data collection

The ODC collected data for the Roermond earthquake from digital broad-band stations, while the KNMI focused on digital short-period data. The selection of broad-band stations was made on the basis of the station inventory of the Federation of Digital broad-band Seismographic Networks (FDSN). The FDSN

acts as a coordinating body (Berry 1988) and regularly upgrades the station inventory. Unfortunately, a similar list is lacking for the short-period stations, although there is an initiative within the ‘transfrontier’-group to start and maintain a station inventory. The KNMI collected short-period data from members of the ‘transfrontier’-group. In addition we collected data from European small-aperture arrays located in Scandinavia (ARCESS, NORESS, FINESS; Ringdahl 1991) and Germany (GERESS; Harjes 1990). These arrays consist of three rings of short-period sensors complemented with one broad-band sensor. An overview of all contributing stations is given in Table 1 and Figs 1A, B. Although the number of digital, short-

period stations exceeds the number of broad-band stations, the favorable azimuthal coverage of broad-band stations for the Roermond event is remarkable.

Major contributing networks include the GEO-SCOPE (Romanowicz et al. 1984) and IRIS (Smith 1986) global networks. On a more regional scale, but still involving many countries, the MedNet network (Boschi et al. 1988) contributed, as well as regional national networks including the German Regional Seismograph Network (GRSN; Hanka 1990), the Graefenberg array (Buttkus et al. 1986) and the LDG network (Massinon & Plantet 1976). Finally, the mobile NARS array (Dost et al. 1984) contributed.

A selection of the data is displayed in Figs 2A, B. Note that each channel is scaled and therefore absolute amplitude cannot be compared between different channels. This is to avoid dominance in the plots of nearby stations (e.g. station Bochum, Germany). Also, some short-period stations did not report accurate station calibrations. Since instrument response information is crucial, it is recommended that either response information is included in a station inventory or that a separate station book is maintained, as is done by the FDSN and GSE. At epicentral distances between 100 and 1500 km there is a noticeable difference between modern broad-band and short-period seismographs. Most of the short-period data channels were saturated, whereas the majority of the permanent broad-band stations recorded the event on scale. Although understandable, since there is a difference in objective of these stations, it can easily be avoided. In nearly all broad-band seismograms a prominent feature is a well-developed surface-wave train with a dominant frequency of 0.05 Hz. Toward higher frequencies, the dispersion of this wave train can be followed up to at least 0.1 Hz. Between 0.1 and 1 Hz higher-mode surface-wave energy is visible (Fig. 3). These waves sample mainly the crust and can be used to infer valuable information on the 3-D structure. In short-period data this information is lost due to the frequency-band limitation.

### Digital seismograph instrumentation

In this section we compare for the first time the seismograph transfer functions (responses) for most existing European digital seismograph stations. This information is essential in the evaluation of data from different stations or networks. In Figs 4A, B the responses of a

selection of stations are shown. If we refer to response in this section, we mean the amplitude response.

### Bandwidth

Most broad-band stations are characterized by a response that is flat to velocity in the frequency range between 0.05 and 5 Hz. There is a considerable difference in response in the higher and lower part of this frequency band between different kinds of broad-band stations. Typically, short-period stations are characterized by a response that is flat to velocity between 1 and 15 Hz. The seismic sensor determines in most cases the low-frequency cut-off. Station SSB (STS-1 Very Broad-Band (VBB) sensor; cut-off a 0.0028 Hz) and the stations of the GRSN (STS-2 VBB sensor; cut-off at 0.0083 Hz) extend their flat response to lower frequencies. The cut-off to the higher frequencies is determined by the sampling rate, the sensor or both. Modern stations, like the GRSN stations and GERESS broad-band station GEC2, make use of digital filtering to extend the flat part of the passband as far as possible. In this way a response curve that is flat to velocity up to 80% of the Nyquist frequency can be realized instead of < 50% with conventional analog filtering. It is interesting to note that the GRSN stations have a high-frequency passband that is similar to the short-period BGS stations. The passband could be extended up to 32 Hz due to the use of STS-2 sensors.

### Gain and dynamic range

The applied gain lies between  $10^7$  and  $10^9$  counts/m/s and does not differ considerably between broad-band and short-period stations. The only exceptions are station KHC, most LDG stations and stations from the GERESS array. Out of the 22 LDG stations in France, five have a high- and low-gain short-period vertical channel (SP-Z), the other stations operate at high-gain only. All but one high-gain recording are saturated in case of the Roermond event, three low-gain recordings are on scale, while the remaining two low-gain recordings show saturation at the surface waves. The GERESS short-period stations have a gain that is even higher than the LDG high-gain stations. However, GERESS stations are equipped with 24-bit Analog to Digital (A/D) converters, which are less likely to saturate. In the case of the Roermond event the LDG low-gain channels are saturated for epicentral distances less than approximately 400 km. For BGS stations this occurs at distances smaller than 700 km, while the

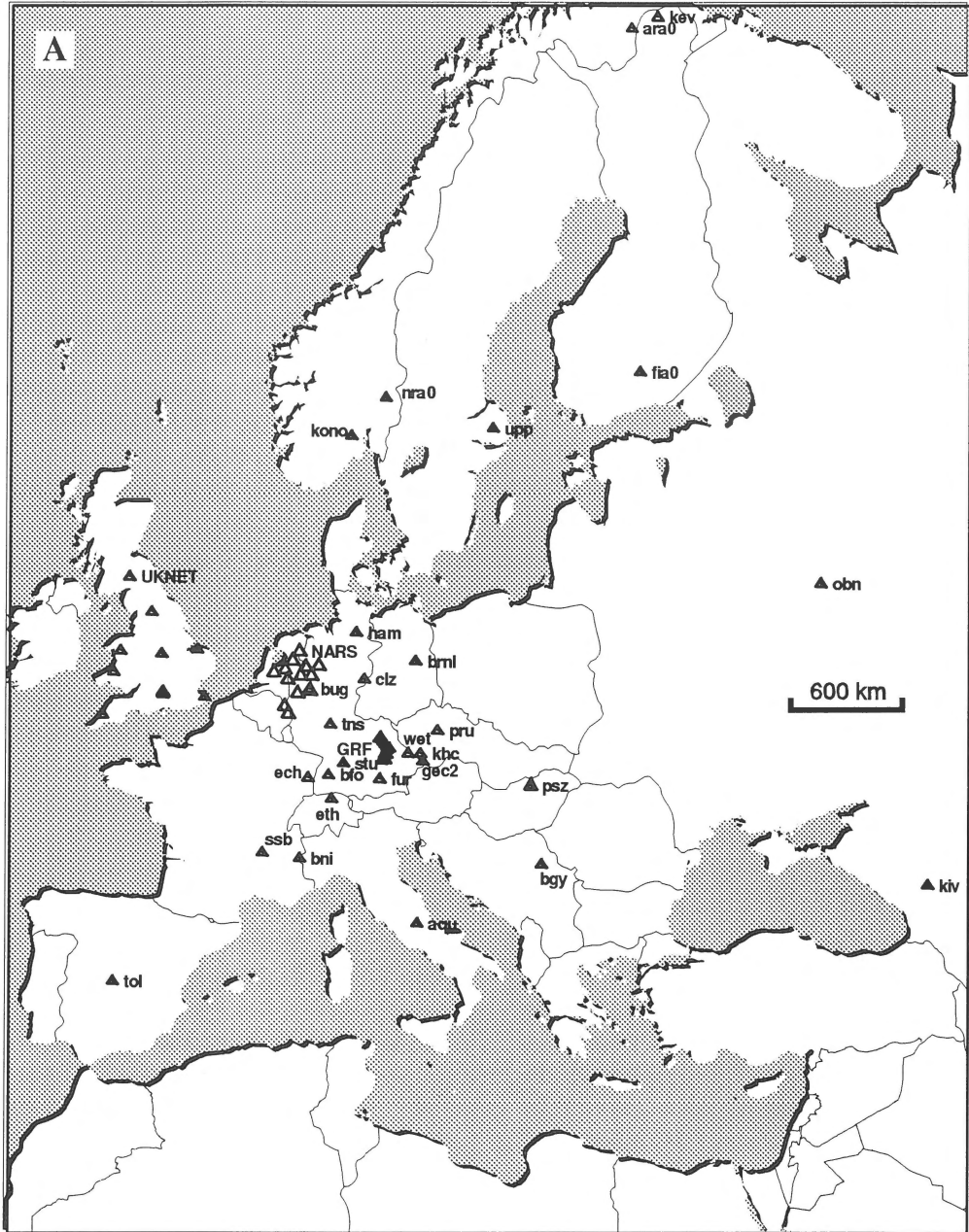


Fig. 1.

GERESS short-period recordings at 600 km distance still record on scale. For the broad-band UKNET, saturation occurs up to distances around 600 km. Nearly all portable NARS stations show a saturation of the first stage of the pre-amplifier at the S-onset (Paulssen et al. 1992).

Summarizing, in case of the Roermond event, many stations show saturation, mainly due to the limited

dynamic range of the A/D converters and the use of high gains. An exception is the GRSN, that recorded the event on scale at a distance of 100 km (station BUG). In this station a modern 24-bit digitizer is used in combination with a low-noise broad-band sensor (STS-2). The full dynamic range of the sensor (140 db) can be recorded without a loss in resolution (Hanka 1991). Presently, affordable dataloggers are developed

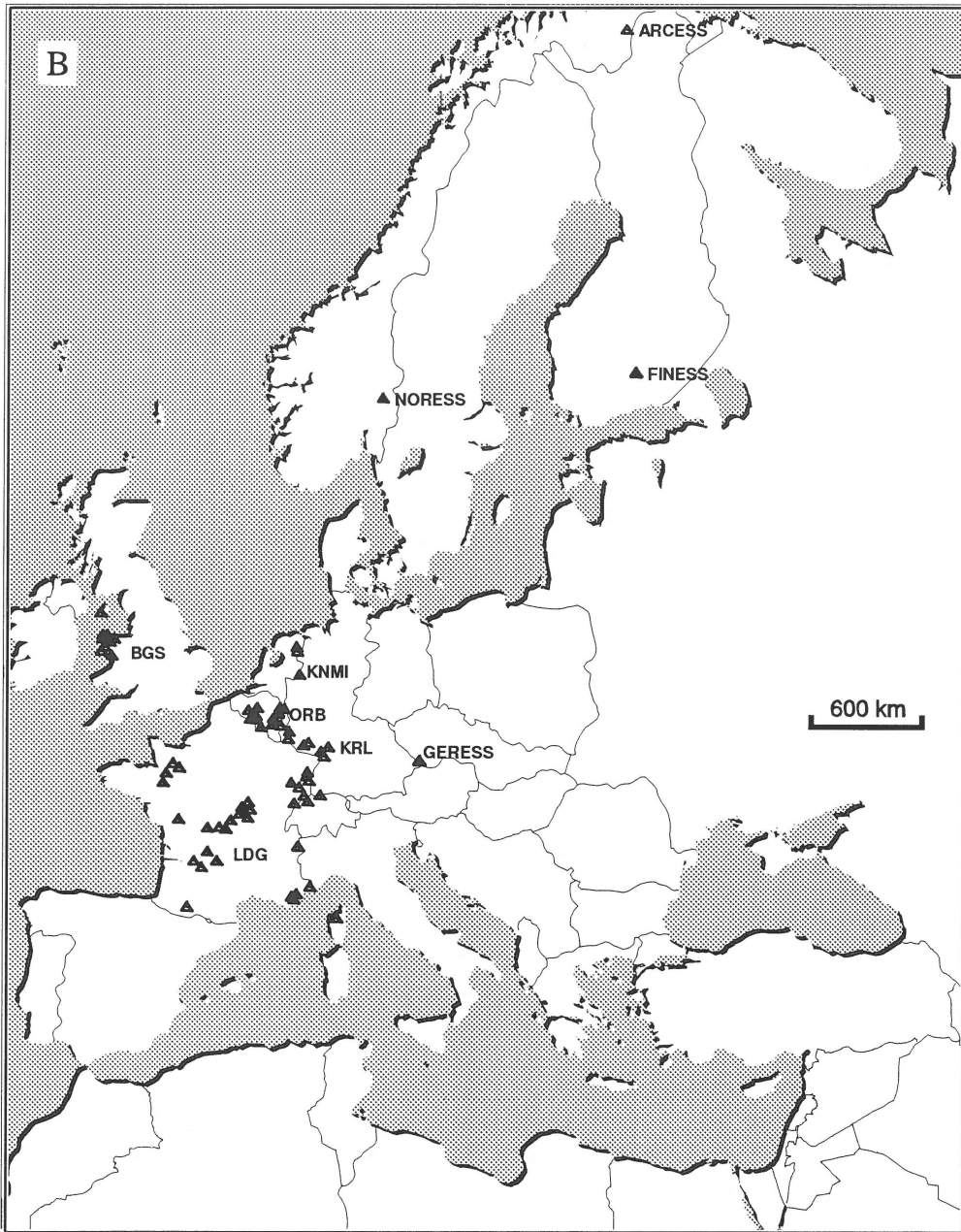


Fig. 1. Overview of digital, broad-band (A) and short-period (B) stations in the ESC-defined European region that contributed their data for the Roermond event to the ODC and the KNMI (see also Table 1 and the Appendix).

with analog to digital converters that have at least 20-bit resolution.

In conclusion, the majority of the currently deployed digital seismograph stations, especially the short-period stations, show a lack of dynamic range in their recording system. It is strongly recommended to upgrade the currently used data acquisition systems. Also, it is recommended to initiate and maintain an

inventory of existing digital seismograph stations in Europe. This inventory should include station location, a short but sufficient description of the recording system (number of bits recorded and dynamic range; on-line accessibility) and at least a rough description of the response (e.g. flat to velocity in a specified frequency range with the corresponding gain).

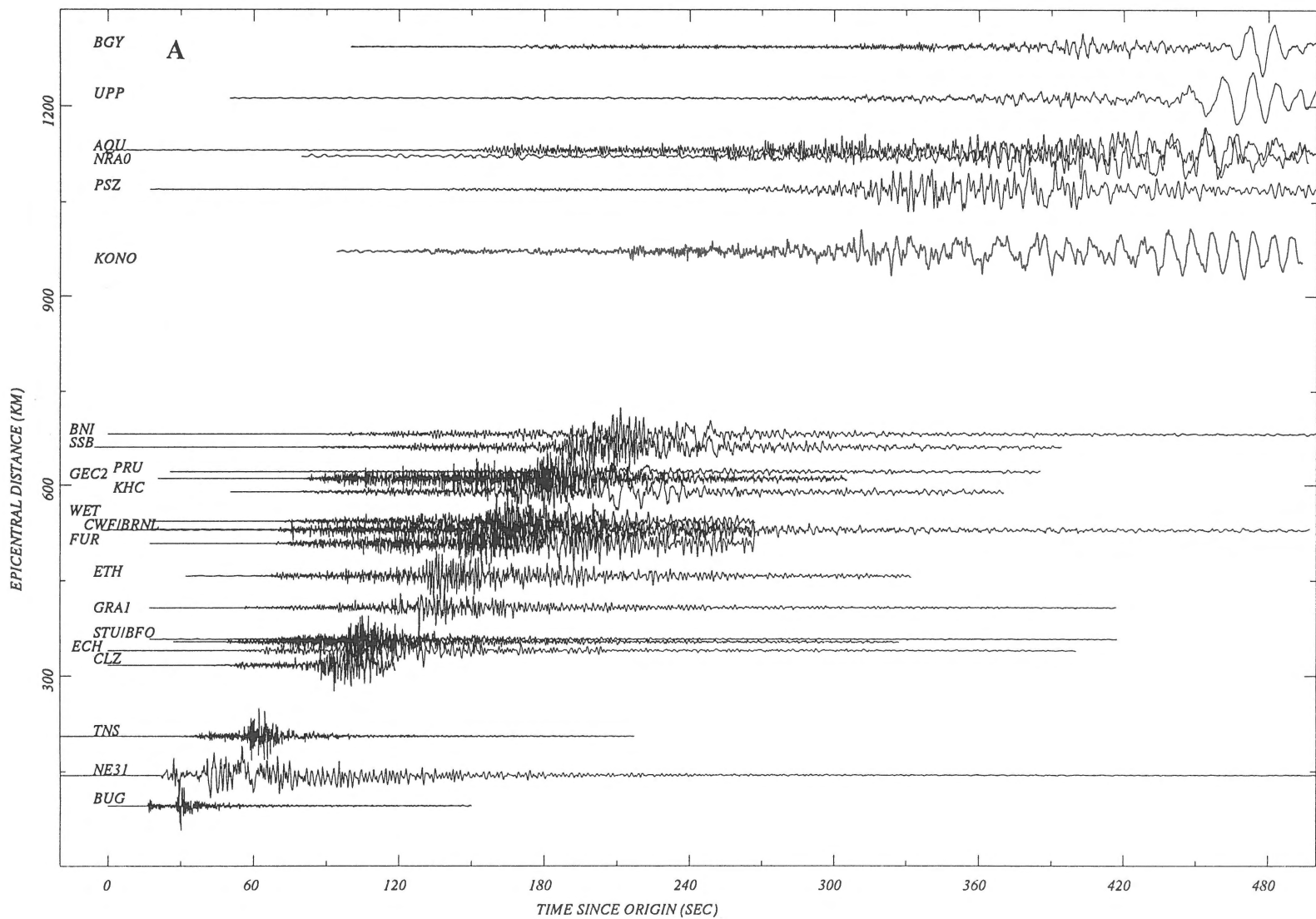


Fig. 2.

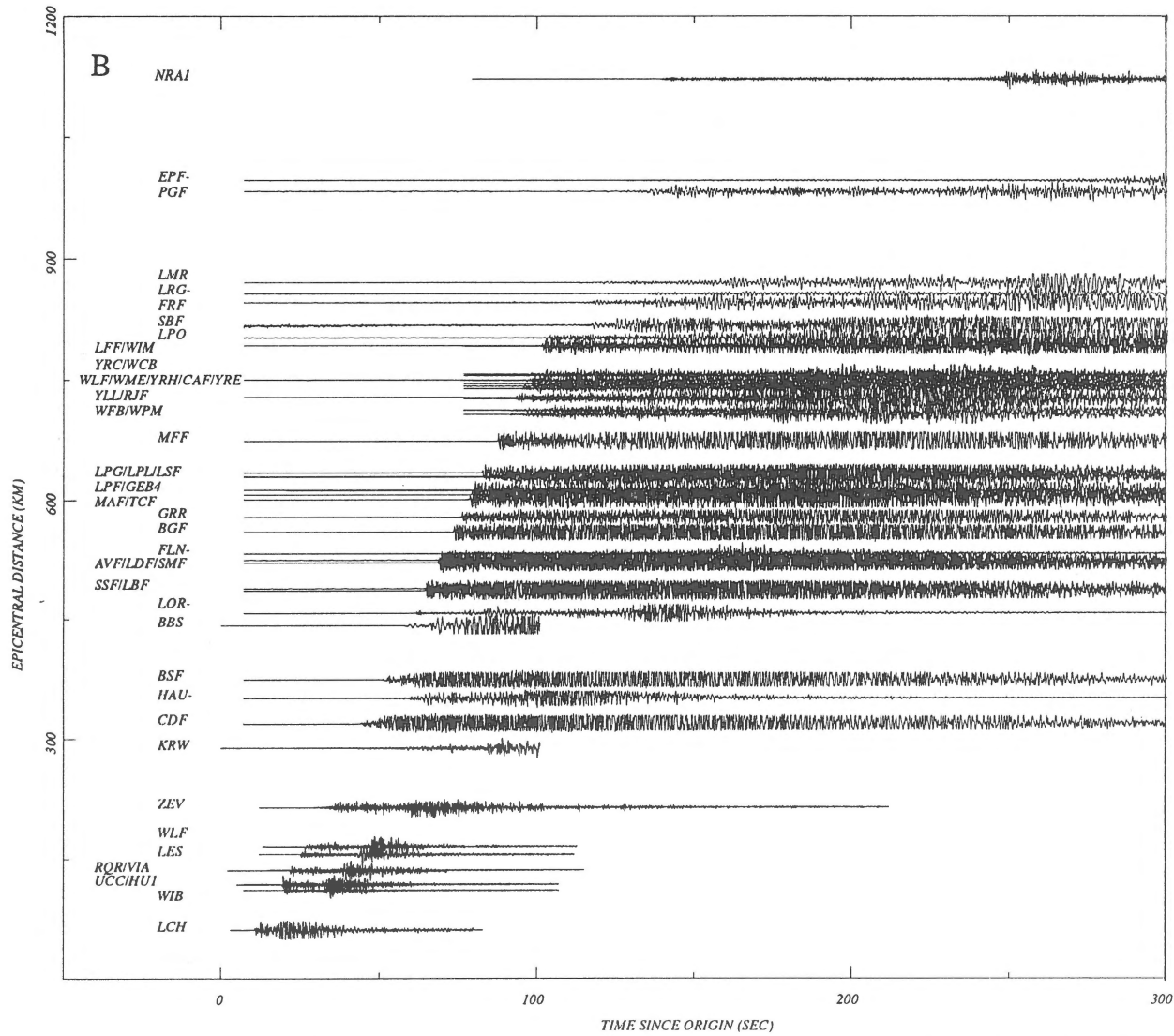


Fig. 2. Overview of (A) broad-band and (B) short-period digital waveform data of the Roermond event as a function of epicentral distance. Data are displayed in the distance range 100–1300 km. Amplitude scaling is performed on each record separately (relative scaling). For station details see Fig. 1 and Table 1.

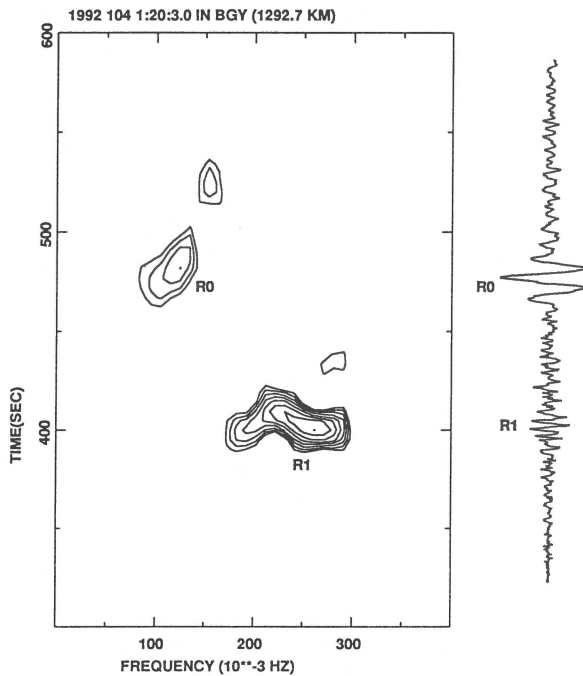


Fig. 3. Multiple-filter diagram of the vertical component of MedNet station BGY. Energy from the Airy phase of the fundamental mode Rayleigh wave (R0) can be seen around 100 mHz, and the higher-mode energy (R1) from 200 to 300 mHz. The data trace outside the diagram is low-pass filtered with a corner frequency at 300 mHz.

## Data format

Seismological waveform data of the Roermond earthquake were collected in a wide variety of recording formats. The ODC is in the process of converting all data streams to the standard archival format for broad-band data: SEED. Most networks or stations contributed the data in their own local format (e.g. KHC, STU, ETH, UPS, LDG, BGS), while major networks (IRIS, GEOSCOPE, MedNet) provide their data in SEED, however with a time delay ranging from several months up to years. For rapid data exchange an analysis format is often used (e.g. SAC).

There is some confusion among data users regarding data formats. We facilitate the understanding by introducing a classification. Data formats fall roughly into four classes:

1. Local formats used at station-sites and networks (e.g. ESSTF, GDSN format),
2. Formats used in standard analysis packages (e.g. SAC),
3. Archival and exchange formats (e.g. SEED, GSE),
4. Database systems (e.g. SUDS).

These classes show a hierarchical structure. Class 4 forms a superset of all other classes. This means that classes 1–3 can be deduced from class 4. The same applies for classes 1 and 2 with respect to class 3, although conversion to level 1 will not often be required. All data center conversions are intended to move upwards 1 → 4 into the hierarchy, aiming at data storage. Software to convert data from class 4 to 3, and from class 3 to 2, is widely available through the ODC or IRIS Data Management Center (DMC).

This data format hierarchy also explains why there are so many formats. Class 1 depends on the designer of the data acquisition system. Until recently there was no real need for designers to adhere to a standard recording format. Display and analysis software (class 2) was proprietary and marketed specifically for certain formats. Station operators who did not develop their own analysis programs, started to convert local formats into other formats (for example: SAC). The standard analysis packages usually provide subroutines that make conversion of local formats easier.

Some local station formats like the GDSN format are used by a global network (DWWSSN). Since for many years this was the only existing global network, the GDSN format acted as a de facto standard, although it was not designed as one. International data exchange within the FDSN and GSE groups, both dealing with many different global and regional networks, initiated the need to define standard exchange formats. Since the available digital data set has increased dramatically in recent years (from 600 Mbyte annually in 1980 to 300 Gbyte in 1992) common database systems appear as a superset of the standard exchange formats.

An example of a standard archival format (class 3) is SEED. This format was defined within a working group of FDSN and accepted by, and implemented at all major broad-band networks and data centers. ODC and IRIS DMC can provide software to read SEED data and convert it to class 2 formats like SAC. A reference reader, developed and maintained at the IRIS DMC, is easily updated with new output formats. Also, software is available to convert class 1 formats to SEED and even to convert other class 3 formats, like the GSE format, to SEED. Conversion software is written and maintained by the ODC, based on a toolkit developed at the IRIS DMC. The existence and maintenance of this software is essential for an efficient exchange of data. Presently, also some regional networks that operate short-period instruments (e.g. Washington network) are starting to use SEED for data archival.

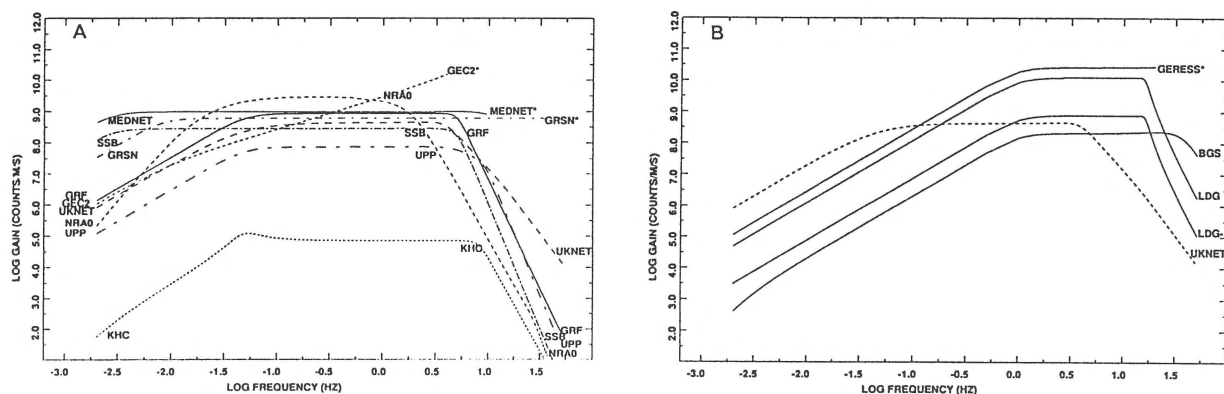


Fig. 4. Overview of transfer functions for selected broad-band (A) and short-period (B) stations. Only amplitude information is displayed. Stations marked by an asterisk (\*) apply digital filtering. Their response is shown up to 80% of the Nyquist frequency. For station details see Fig. 1 and Table 1.

It is recommended to consider SEED as the standard archival (class 3) format also for short-period data. SEED is designed as an exchange format, is accepted as a standard by the entire broad-band community and is supported by software that is freely available to any user. An evaluation of formats presently used at short-period networks is essential at this point to see if there is any need to add features to SEED.

### Data access

Generally, seismologists prefer to have access to waveform data in two ways: a) on-line, as soon as possible and as many stations as possible; b) off-line, a complete dataset on an efficient medium (CD-ROM, Exabyte, DAT). In both cases it should be clear to the user what time delay is acceptable between the origin time of the event and the arrival of the data from a specific station into the accessible data set.

#### Rapid access, *gopher* (on-line)

The ODC currently operates an automatic data request manager, named 'gopher'. Gopher has been developed for IRIS by Steve Malone (Univ. of Washington). A quick determination of a large event (magnitude > 5.5) by the National Earthquake Information Service (NEIS) in Golden (USA) is usually done within one hour after the event origin time. A message is then sent to the IRIS DMC in Seattle (USA) by elec-

tronic mail, where it automatically triggers a system that requests data from several 'open' stations within and outside the USA. Open stations can be directly accessed by any user. The same message is forwarded to the ODC and other regional centers around the world. Each of these centers requests data automatically from stations in its region. These data requests to the stations are handled by modems. Finally the collected data are exchanged between data centers through efficient data communication channels (internet).

Data on gopher are on-line available within a few hours after the event. Presently, the system provides the data in SAC format, but this will in future be changed to SEED volumes. Currently, the gopher system is dedicated to stations that are of interest to the FDSN. However, the system can easily be extended to include regional stations. Also, a trigger from the European data center for parametric data (EMSC; phase readings, locations) can easily be incorporated.

#### Complete data set (off-line)

The ODC collects broad-band data from a number of stations. Data are quality-controlled and made available in a standard format (SEED). This data set contains also data from stations that are inaccessible on-line and therefore excluded from the gopher system. Presently, data is available on CD-ROM for the years 1988 and 1989 to members of ORFEUS and through the National Earthquake Information Centre (NEIC). Data

for the period 1980–1987 are available on CD-ROM in the GDSN format.

### *Autodrm*

The way a user wants to have on-line data access depends for a large part on the availability of data communications to this user. Apart from directly logging in to the machine that presumably contains the data requested (on-line data access), one can also use an off-line system: the automatic data request manager (autodrm). From a user perspective, the autodrm is a message in a standardized format that contains all information for a data center to comply with a data request (station code(s) and time window). The message is then sent by electronic mail to a specific node in the autodrm network (i.e. a data center), where a system automatically processes the request. Such a request takes advantage of the fact that the data center knows where to find the data. A prototype autodrm system for the GSE is already developed at the Eidgenössische Technische Hochschule, Zürich, Switzerland (Kradolfer 1993), and a similar system is under construction within the FDSN. There is coordination between GSE and FDSN on this issue.

In conclusion, rapid access to station data requires the availability of open stations. It is recommended to implement such stations and restrict the openness to a regional data center that is responsible for data collection. This ensures that the station manager can still access his/her own station after a major earthquake. Users can then access the data center to view and transfer the complete data set. Furthermore it is recommended that regional networks consider the use of an autodrm and start to become involved in the development of an autodrm standard.

### **Conclusions**

The ODC and the seismological section of the KNMI collected a nearly complete set of digital waveform data from the Roermond earthquake. This effort offered a unique opportunity to evaluate the current status of digital data recording and data exchange within the seismological community in Europe. Due to recent developments, users of seismological waveform data can have fast and easy access to large data bases, provided the data flow is coordinated, and format and exchange procedures are standardized. The FDSN and

GSE groups are working towards standardization and it is time the regional networks join this effort.

An evaluation of the available data for the Roermond event showed that the majority of the currently used data acquisition systems require an upgrade to higher dynamic range. It is useful to extend the bandwidth of short-period sensors to lower frequencies. Broad-band sensors may extend the passband to higher frequencies by using digital filters. The set-up and maintenance of a station inventory of digital stations forms the basis of a well-organized data exchange, together with a standardization of archival formats. For short-period data both are lacking at present.

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### **Appendix**

#### *Abbreviations*

A/D converter	Analog to Digital converter.
Autodrm	Automated Data Request Manager.
BGS	British Geological Survey.
CD-ROM	Compact Disc Read Only Medium.
DAT	Digital Audio Tape.
DMC	Data Management Center.
DWWSSN	Digital World Wide Standard Station Network.
EMSC	European Mediterranean Seismological Center.
ESC	European Seismological Commission.
ESSTF	Format used in Lennartz data acquisition systems.
FDSN	Federation of Digital broad-band Seismograph Networks.
GDSN	Global Digital Seismograph Network.
GRSN	German Regional Seismograph Network.
GSE	Group of Scientific Experts of the Geneva conference on disarmament.
IDA	International Deployment of Accelerometers.
IRIS	Incorporated Research Institutes for Seismology.
KNMI	Royal Netherlands Meteorological Institute.
MedNet	Mediterranean Network.
NARS	Network of Autonomously Recording Stations.
NEIC	National Earthquake Information Center.
NEIS	National Earthquake Information Service.
LDG	Laboratoire de Détection et de Géophysique.
ODC	ORFEUS Data Center.
ORB	Royal Observatory of Belgium.

ORFEUS	Observatories and Research Facilities for European Seismology.
SAC	Seismic Analysis Code.
SEED	Standard for the Exchange of Earthquake Data.
SUDS	Seismic Unified Data System (Ward 1992).
UKNET	United Kingdom seismograph Network.
VBB	Very Broad Band.

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