

Seismology

Sysmology

Seismology is the basic science concerning earth movements and is connected to the solid ground under our feet that can be shaky from time to time. The years 2001 and 2002 showed again that the earth has not given up its movements. The earthquake of magnitude 4.9 near Alsdorf on 22 July 2002 in Germany just across the border with the

Netherlands is a recent example. The two years 2001 and 2002 were productive in many ways, building on the investments both in knowledge and equipment in previous years. Especially the work related to infrasound has drawn much attention internationally.

Observations

Monitoring natural seismicity

In the southeastern part of the Netherlands earthquakes are related to the tectonic regime of the Lower Rhine Embayment, mainly in the Roer Valley Graben. In the period under review 17 earthquakes took place within the political borders of the Netherlands, i.e. 8 in 2001 and 9 in 2002. Of these earthquakes 8 occurred near Roermond, which shows that this region is still active after the large event of magnitude 5.8 in 1992.

The large swarm of earthquakes near Voerendaal that already started in December 2000 continued in 2001 and 2002. Near Voerendaal, 132 earthquakes occurred in 2001 and 4 in 2002. The magnitude varies between -0.1 and 3.9. There were 6 events with magnitude 3.0 or higher. The strongest event, with magnitude 3.9, occurred on June 23, 2001.

On July 22, 2002, a large earthquake with magnitude 4.9 occurred near Alsdorf, just across the border in Germany. In the first 6 hours after the event 13 after-shocks were recorded with a maximum magnitude of 2.5. Just after the event a questionnaire was put on the KNMI Internet site where people could report whether they felt the

earthquake or not. In one week we received almost 4000 reactions, from which we could conclude that the earthquake was felt in the whole country. The maximum intensity for this earthquake was VII and damage to buildings was reported.

Also 7 earthquakes occurred in 2000 and 2001 in the North Sea, with magnitudes varying between 1.3 and 4.5. It is not clear if these events are natural or induced. An example of an interesting and large event is the one near the Ekofisk gas field on May 7, 2001, with a magnitude of 4.5. In any case it is clear that the North Sea has a low level of seismic activity, also on the continental margin of the Netherlands.

Monitoring gas production related earthquakes in Groningen, Drenthe and Noord-Holland

In 2001 21 earthquakes have been recorded and located. Magnitudes vary between -0.2 and 3.5. Of special interest were two events near Alkmaar in September 2001, with magnitude 3.5, the largest induced event ever recorded in the Netherlands, and magnitude 3.2. These two events follow two previous events in the region in 1994, and could be attributed to one fault within the Bergermeer

gas field. In addition to these events, one event occurred for the first time at the edge of the Bergen gas field. These Alkmaar events caused damage in the region. The statistics of the Alkmaar events is not in line with the general rule concerning the distribution of magnitudes. After these events 3 accelerometers were installed in the region by the end of 2002 to be prepared for future events.

NAM conducted a down-hole micro-earthquake survey in the Roswinkel area with a set of sensors at reservoir level (2000 m depth) for a period of two weeks. About 40 events were recorded at magnitudes between -6 and -2 . Accurate locations coincided with results from KNMI locations for the larger events and confirmed a depth of 2 km.

In 2002 25 events have been recorded and located, with magnitudes ranging from 0.0 to 2.2. The Roswinkel area remained active, as well as the Annerveen area. NAM also carried out a down-hole micro-earthquake experiment in close co-operation with KNMI, with respect to the Annerveen gas field. Although only 10 events were recorded, this experiment did generate additional information of use in the interpretation of the larger events.

Development of the seismometer network

In June 2001 a Quanterra Q4120 6-channel datalogger and a Streckeisen STS-2 broadband seismic sensor were installed at seismic station Heimansgroeve (HGN). In 2002 two Applied Geomechanics tiltmeters and a Lacoste-Romberg gravimeter were installed and connected to the same datalogger. The analog outputs of these seismic and geophysical sensors are digitised by the Quanterra datalogger and transmitted in real-time to KNMI over Internet. In January 2002 a calibration board was installed in the datalogger to calibrate the STS-2 seismic sensor at regular intervals. In early 2003 the STS-2 will be replaced by the Streckeisen STS-1 very broadband seismic sensor, which is operational at HGN since 1993.

Two Quanterra Q730 datalogger systems were configured in 2002 to deploy two new seismic broadband stations. One system will be installed at station Winterswijk B (WTSB) in early 2003 to modernise the acquisition system and to make WTSB a contributing station in the VEBSN. Two Quanterra Q330 dataloggers were purchased in 2001, which will be deployed in the southern part of the Netherlands as mobile seismic stations together with Streckeisen STS-2 broadband sensors.

In 2002 a real-time application was developed under Real-Time Linux to send data over Internet to an analog recording system (drum recorder). Even today such an analog system is desirable for real-time visualisation purposes and for monitoring of seismic activity and data quality.

Accelerometers

During the last 5 years a successful programme was carried out to install accelerometers in epicentral areas where earthquakes are to be expected within a relatively short timeframe. Accelerometers are quite useful in the determination of the level of shaking in areas where damage to buildings could occur both due natural and induced events.

Following the start of the earthquake swarm near Voerendaal in December 2000, four accelerometers were deployed in Voerendaal during 2001 and the first half of 2002. This local network recorded 40 earthquakes over 2001 and 2002. The recordings of the largest earthquake, at 23 June 2001 with magnitude 3.9, showed an acceleration of about 1.8 m/s^2 .

During 2001 and 2002 4 new accelerometers were purchased, bringing the total number to 20. This number of stations requires remote access of the instruments, both for maintenance purposes and for retrieval of the data. Therefore the accelerometer stations were successively equipped with GSM dial-up modems during 2001 and 2002. In 2002 3 accelerometers were installed nearby Alkmaar, after the two larger earthquakes in the region.

Instrument testing

Towards the end of 2002 Shell asked KNMI to contribute to a test of different seismic sensors in the frequency range of 1–10 Hz. The site of station HGN was used to conduct this experiment, where in addition to the broad-band sensors (STS-1 and STS-2) also a series of analog and digital micro machined electro-mechanical system (MEMS) sensors were tested, as well as an array of 4.5 Hz geophones at the surface and a high sensitivity geophone in the vault. These MEMS-sensors are ultra small solid-state devices that can detect mechanical vibrations and are used, for example, as trigger devices in automobile airbags. The instruments recorded continuously for one week and at the end a 16 tons Vibrator truck was arranged to allow for an active source. The experiment is evaluated early 2003 and a report will be prepared.

Research

Regional seismicity

In order to have a fast and efficient access to historical earthquake data in the region a Geographical Information System (GIS) was further expanded. Apart from seismicity data (phases, locations), the GIS system was extended with information on (active) faults and gas fields. For some regions also subsidence data were added and data from micro earthquake surveys at reservoir levels (NAM). This system is also used for the reanalysis of old events.

During 2001 and 2002 an earthquake swarm occurred near Voerendaal. This swarm started in December 2000 and included a series of events of magnitude up to 3.9 (June 23, 2001). A study started on all aspects of this swarm, including the statistics and b-value, the source mechanism and accurate locations using correlation techniques. First results show a normal faulting mechanism, in accordance with the regional pattern. Locations show a migration of locations along the fault, which changes from a SE-NW direction to an E-W direction near Voerendaal.

In order to improve locations, an effort was undertaken to improve the 1D crustal model in the Roer Valley Rift System together with colleagues from Germany and Belgium. Within this co-operation KNMI focused on the calculation of 'receiver functions' for the broadband station HGN and the short period stations available (Valkenburg (VKB), Rolduc (RDC) and Schinveld (SCHN)). First results show significant variations in crustal structure within a small distance (10–20km) from station HGN. The influence of dipping layers is visible and is subject of further research.

Research into induced events in the northern part of the Netherlands focused on the two events near Alkmaar and the continued activity near Roswinkel. The events near Alkmaar showed continued activity along the same fault compared to the previous events in 1994. The mechanism for this event showed a reactivation of an existing normal fault, but its movement is reversed, in line with the fact that gas is extracted from the upper block. In the case of Roswinkel, results from micro earthquake monitoring operated by the NAM showed seismicity in line with the locations from the shallow boreholes. This confirmed the accuracy of the relative locations for the larger events determined by KNMI.

Local site effects

The effects of the shaking during an earthquake can be enhanced or diminished due to local circumstances such as the composition of the shallow subsurface. Shallow is in most cases the first 25–50 meters. These shallow surface effects are known as site effects in seismology and play an important role in the determination of seismic hazard. In previous years, detailed velocity models were made at two locations equipped with borehole stations. From these data the site effects could be calculated. Now, a more engineering type of approach is under study to produce eventually maps on which the site effects are plotted. This is foreseen to be done by the analysis of shallow borehole data and by the measurement of S-wave velocity structure with small arrays.

Seismic hazard analysis

International developments towards a more sophisticated society and a more intricate infrastructure are also relevant in the Netherlands. The consequence is a larger vulnerability towards different natural risks, like earthquake related risks, and this has been recognised by national law enforcing institutes. For example, the new Dutch exploration law that will enter into force January 1, 2003, requires an extensive mining plan, including, specifically, an (induced) earthquake risk assessment. Therefore, a project was initiated to reassess seismic hazard in the Netherlands and its immediate surroundings. This reassessment involves a probabilistic characterisation of the ground acceleration and ground velocity to be expected in the Netherlands due to tectonic and induced seismicity. In a number of cases a deterministic approach will be followed. This work is coordinated with among others the NITG. Within an informal discussion group, 'Technisch Platform Aardbevingen' (TPA), KNMI discusses research initiatives in a broader forum with other research institutes and larger exploration companies.

Furthermore, the Seismology Division has been requested to perform international expert reviews on seismic hazard studies for, among others, Shell Global Solutions and specific hazard studies for governmental organisations, like the Ministry of Foreign Affairs and the Ministry of Public Transport and Water Management. The latter study was an assessment of the risk to river dikes in the case of a severe loading by high water levels. A report was published in December 2002.

Modelling of seismic sources

Earthquake processes show chaotic behaviour and are therefore difficult to describe deterministically. Still, good observations close to the rupture area are an important prerequisite to understand these processes better. In the Netherlands, we have no realistic options to study tectonic earthquakes at the depths they occur (around 12–17 km). However, induced seismicity occurs at much shallower depths near the gas reservoirs to be exploited. The Division has set up a co-operation with both the NAM and Shell Research to study micro earthquakes jointly with KNMI borehole sensors and sensors deployed at depths corresponding to the occurrence of induced earthquakes. While the NAM and Shell Research are interested in micro earthquakes for reservoir characterisation, KNMI is interested in these measurements to model the recorded micro earthquakes. Within this co-operation the Division has also given a three days seminar on seismology, specifically related to source processes. In parallel the Division maintains a capability to perform numerical modelling using Boundary Element Methodologies.

Attenuation of seismic waves

Attenuation is an important factor for the calculation of seismic hazard. The attenuation of seismic waves in the southern part of the Netherlands (Limburg) was determined. Attenuation can be represented by a quality factor Q , which stands for the damping of an oscillation in general, but here more specifically for the damping of seismic waves. One way to determine this quality factor is the use of coda waves. Coda waves show up in seismograms as the tail of a primary (P) or secondary (S) arrival having an envelope whose amplitude gradually decreases with time. They are composed of a superposition of waves scattered by heterogeneities in the earth. From the coda envelope the quality factor can be calculated. We used local earthquakes from the southern part of the Netherlands and from Belgium and Germany, recorded at permanent and temporary digital seismograph stations in these countries. The results show a significant difference in Q between small (< 25 km) epicentral distances and larger ones. Moreover, intrinsic absorption dominates over scattering. Given these and other observations we deduce that the lower crust and the upper mantle have a significant effect on the seismic coda. Better modelling is needed.

Comprehensive Nuclear-Test-Ban Treaty (CTBT)

The activities in the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) concentrated mainly

on advisory work for the Ministry of Foreign Affairs and on the monitoring aspects of infrasound. The contribution in the area of the infrasound monitoring technique is focussed on source characterisation and array processing. Both are fundamental in the operation of the International Monitoring System (IMS) to verify the Treaty. This work is highly visible and resulted in a workshop organised in the Netherlands in November 2002. The work on the Netherlands National Data Centre (NDC) was not much advanced in the light of the political situation. However, Canada and the Netherlands will be the open and free accessible data centres for infrasound. In the beginning of 2003 the Netherlands National Data Centre is formally installed at the request of the Ministry of Foreign Affairs.

Infrasound

Infrasound is inaudible low frequency sound with air pressure fluctuations in the range from 0.005 to 40 Hz. The Seismology Division measures infrasound to distinguish between earthquakes signals and signals from atmospheric sources. Infrasound from a sonic boom, for example, can cause similar vibrations in houses as those associated with an earthquake. Furthermore, infrasound measurement is one of the verification techniques of the CTBT. Research is carried out to scientifically support the CTBT with the unique network of sensors in the Netherlands.

Arrays are operated in De Bilt (DBN) and Deelen (DIA). DBN consist of six in-house developed microbarometers laid out over an area of 70 x 70 meters, for DIA 16 microbarometers are used in an area of 1500 x 1500 meters. A third array in Witteveen is currently being upgraded.

The volcanic explosions of Mount Etna in Italy were recorded in the Netherlands during the summer of 2001. Also several bolides were detected and localized from the North Sea to South Germany. Bolides generate infrasound because they penetrate the Earth's atmosphere at super-sonic speeds and sometimes thermally explode at the end of their trajectory. A bolide of 26 kT TNT equivalent was detected over the Mediterranean Sea. Infrasound from the Concorde and military fighter jets are measured on a daily basis.

EC-project MEREDIAN

The Mediterranean-European Rapid Earthquake Data Information and Archiving Network (MEREDIAN) is an EC-project within the 5th

framework programme under 'Support for Research Infrastructure' and is coordinated by the Seismology Division. Goal of this project is to make earthquake waveform data, primarily from European high-quality seismograph stations, rapidly and effectively available for basic research and studies on earthquake effects mitigation. Ten European national seismological observatories are presently participating in this project, i.e. in Austria, France, Germany, Greece, Italy, Netherlands, Norway, Slovenia, Spain and Switzerland. Late 2002 the project has been extended to include eight EC candidate countries: Bulgaria, Czech Republic, Estonia, Hungary, Malta, Poland, Romania and Slovak Republic.

The ORFEUS Data Centre facilities are being significantly upgraded within the MEREDIAN project. The Virtual European Broadband Seismograph Network (VEBSN), i.e. real time data arriving centrally at the ODC from all over Europe and its vicinity, is being realised. New data products, for example rapid event locations and arrival picks, are becoming available. The other consortium members make similar investments at their national observatories.

EC-project EMICES

European-Mediterranean Infrastructure Coordination for Earthquake Seismology (EMICES) is an EC-project under the 5th framework programme under 'Accompanying Measures' and is coordinated by the Seismology Division of KNMI. The goal of this project is to support the MEREDIAN project with the organisation of three workshops; 'Real-time data exchange in Europe', Barcelona, Spain, October 23–25, 2002; 'Distributed, Object Oriented Computing for Seismology', Athens, Greece, 2003 and 'Seismic hazard and data exchange within the Mediterranean', Nicosia, Cyprus, 2003/4. Participants in this project are the EMSC (European-Mediterranean Seismological Centre), Institut

d'Estudis Catalan, Barcelona, Spain, University of Athens, Greece and the Geological Survey of Cyprus.

ORFEUS and the Orfeus Data Centre

Observatories and Research Facilities for European Seismology (ORFEUS) maintained and strengthened its position in the coordination and promotion of broadband seismology in the European-Mediterranean region. During the reporting period 11 corporate founders provided the main funding. The number of paying participants went from 53 in 2001 to 62 in 2002. The data centre has been upgraded with, among others, a new data storage (RAID) system accommodating nearly one terabyte of data and reorganised to meet the requirements of the networking and security specialists at KNMI.

ORFEUS co-ordinating activities have been numerous and can be followed on our web pages <http://orfeus.knmi.nl>, which are kept up-to-date on a daily basis. The Seismological Software Library, maintained by ORFEUS, is presently a well-established global reference for public seismological software (see also the AGU International Handbook of Earthquake and Engineering Seismology, Part A, 2002). July 3–5, 2001 a meeting of European Seismologists in De Bilt was organised to discuss long-term strategies for a European Research Infrastructure in seismology. July 6–10, 2001 a meeting of major European and US data centres was held in De Bilt to coordinate their activities. From November 18–22, 2002 there was an ORFEUS workshop 'Installation and operation of seismic broadband stations' in Istanbul. During 2001 and 2002 4 issues of the ORFEUS Electronic Newsletter have been published on our web pages. Both ORFEUS and the EMSC have started coordinating their European activities during 2002.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

- Demanet, D., L.G. Evers, H. Teerlynck, B. Dost, and D. Jongmans, 2001. *Geophysical investigations along the Peel boundary fault (The Netherlands) for a paleoseismological survey*. *Geol. Mijnb.*, **80** (3-4), 119–127.
- Dirkzwager, J.B., J.D. van Wees, S.A.P.L. Cloetingh, M.C. Geluk, B. Dost and F. Beekman, 2001. *Geo-mechanical and rheological modelling of upper crustal faults and their near surface expression in the Netherlands*. *Glob. Plan. Change*, **27**, 67–88.
- Evers, L.G., H.E. de Bree, H.W. Haak and A.A. Koers, 2001. *The Deelen Infrasound Array for recording sonic booms and events of CTBT interest*. *J. Low Freq. Noise*, **19**, 123–133.

- Evers, L.G. and H.W. Haak, 2001. *Listening to sounds from an exploding meteor and oceanic waves*. *Geophys. Res. Lett.*, **28**, 41–44.
- Gussinklo, H.J., H.W. Haak, R.C.H. Quadvlieg, P.M.F.M. Schutjens and L. Vogelaar, 2001. *Subsidence, Tremors and Society*. *Geol. Mijnb.*, **80** (1), 121–135.
- Thurber, C., C. Trabant, F. Haslinger and R. Hartog, 2001. *Nuclear explosion locations at Balapan, Kazakhstan, nuclear test site: the effects of high-precision arrival times and three-dimensional structure*. *Phys. Earth Plan. Int.*, **123**, 283–301.

2002

- Berg, M. van den, K. Vanneste, B. Dost, A. Lokhorst, M. van Eijk and K. Verbeek, 2002. *Paleoseismic investigations along the Peel boundary fault: geological setting, site selection and trenching results*. *Geol. Mijnb.*, **81**, 39–60.
- Dahlman, O., J. Mackby, S. Mykkeltveit and H. Haak, 2002. *Cheaters Beware*. *Bull. Atomic Scientists*, **58**, 28–35.
- Dineva, S., T. Batllo, D. Mihaylov and T. van Eck, 2002. *Source parameters of four strong earthquakes in Bulgaria and Portugal at the beginning of the 20th century*. *J. Seism.*, **6**, 99–123.
- Trabant, C., C. Thurber and W. Leitz, 2002. *Ground truth seismic events and location capability at Degelen mountain Kazakhstan*. *Phys. Earth Plan. Int.*, **131**, 155–171.

Other scientific publications and reports

2001

- Dost, B., 2001. *Seismiciteit van de Roerdal Slenk en omgeving*. Bijdrage aan: Toelichting bij kaartbladen XIII en XIV; Breda-Valkenswaard en Oss-Roermond. Uitgave NITG-TNO Geologische Atlas van de Diepe Ondergrond van Nederland, 100–102.
- Evers, L.G. and H.W. Haak, 2001. *An optimal infrasound array at Apatity (Russian Federation)*. KNMI Technical Report TR-195.
- Haak, H.W., B. Dost, and F.H. Goutbeek, 2001. *Seismische analyse van de aardbevingen bij Alkmaar op 9 en 10 September en Bergen aan Zee op 10 oktober 2001*. KNMI Technical Report TR-239.
- Haak, H.W., L.G. Evers and M.E. Petit, 2001. *The Deelen Infrasound Array for recording sonic booms and events of CTBT interest*. *Proc. Ninth Annual Int. Symp. Long-Range Sound Propagation*, The Hague, the Netherlands, 14–15 Sept. 2000, 221–228.
- Oonincx, P., R. Sleeman and T. van Eck, 2001. *An application of the DWT in Seismic Data Analysis*. In: A. Petrosian and F. Meyers (Eds), *Wavelets in Signal and Image Analysis*, Kluwer.

2002

- Dost, B. and H.W. Haak, 2002. *A comprehensive description of the KNMI seismological instrumentation*. KNMI Technical Report TR-245.
- Eck, T. van, 2002. *MEREDIAN: an infrastructure for rapid exchange of earthquake waveform data in Europe*. *Proc. EU-MEDIN Workshop on Natural and Technological Hazards*, Brussels, Belgium, 15–17 November 2000, K. Fabbri and M. Yeroyanni (Eds.), European Commission, 56–59.
- Eck, T. van, B. Dost, C. Trabant, R. Sleeman and F.H. Goutbeek, 2002. *Developments at ORFEUS and its Data Center*. *ORFEUS Electronic Newsletter*, **4**, 13.
- Eck, T. van et al., 2002. *Towards a Virtual European Broadband Seismograph Network*. *ORFEUS Electronic Newsletter*, **4**, 5.
- Evers, L.G., 2002. *De doorbroken stilte rondom meteoren*. *Meteoor*, **58**, 2.
- Haak, H.W. and L.G. Evers, 2002. *Infrasound as a tool for CTBT verification*. *VERTIC Yearbook*, 207–221.
- Lee, H.K., Kanamori, H., Jennings, P.C. and C. Kisslinger (Eds.), T. van Eck (coordinator), 2002. *International Handbook of Earthquake and Engineering Seismology, Part A*. Academic Press.
- Sleeman, R. and T. van Eck, 2002. *Single station real-time P and S-phase pickers for seismic observatories. Methods and applications of signal processing in seismic network operations*. *Lecture Notes in Earth Sciences*, **98**, 173–189.

Number of national presentations

2001: 9

2002: 11

Number of international presentations

2001: 13

2002: 28

Education and organisation of workshops

2001

Eck, T. van, Datacenter coordination meeting, KNMI, De Bilt, the Netherlands, 6–10 October, organiser.

Eck, T. van, Second MEREDIAN meeting INGV, Rome, Italy, 1–2 October, organiser.

Eck, T. van, B. Dost and F.H. Goutbeek, Strategy meeting on data exchange for European Seismology, KNMI, De Bilt, the Netherlands, 3–5 July, organisers.

Eck, T. van, First MEREDIAN Meeting, KNMI, De Bilt, the Netherlands, 1–2 February, organiser.

2002

Eck, T. van, Orfeus workshop Installation and operation of broadband seismic stations, Istanbul, Turkey, 18–20 November, organiser.

Eck, T. van, B. Dost, Th. de Crook and F.H. Goutbeek, 3-day Course for employees of NAM and Shell Research Lab., Introduction to seismology, De Bilt, the Netherlands, 27 February–1 March, organisers.

Eck, T. van and F.H. Goutbeek, EMICES workshop Real-time data exchange in Europe, Barcelona, Spain, 23–25 October, organisers.

Eck, T. van and F.H. Goutbeek, Third MEREDIAN meeting, Barcelona, Spain, 20–21 October, organisers.

Evers, L.G., Infrasound Technology Workshop, De Bilt, the Netherlands, 28–31 October, organiser.

Committees

Crook, Th. de, Commissie Aardbevingen van het Nederlands Normalisatie Instituut, member.

Dost, B., ESC WG Data centres and data exchange, chairman.

Dost, B., Federation of Digital broad-band Seismograph Networks (FDSN), member Executive Committee.

Dost, B., Orfeus Data Centre, director.

Dost, B., Subcommission Bodembeweging en Zeespiegelvariatie of the Nederlandse Commissie voor Geodesie, member.

Dost, B., User panel of Seismological Research Emphasizing Array Technologies (SRESAT) project, member.

Dost, B., Working Group on Data Exchange of the FDSN, chairman.

Eck, T. van, EC fifth framework proposals, evaluator.

Eck, T. van, EC-project EMICES (EVRI-2001-00030), coordinator.

Eck, T. van, EC-project MEREDIAN (EVRI-2000-40007), coordinator.

Eck, T. van, FDSN Working group 3, Seismological software, member.

Eck, T. van, Observatories and Research Facilities for European Seismology (ORFEUS), secretary-general.

Eck, T. van, ORFEUS Working group 1, Station siting, secretary.

Eck, T. van, ORFEUS Working group 2, Technical assistance, secretary.

Eck, T. van, ORFEUS Working group 3, Mobile equipment, secretary.

Eck, T. van, ORFEUS Working group 4, Seismological software, secretary.

Eck, T. van, Technisch Platform Aardbevingen, member.

Haak, H.W., beoordelingscommissie ALW-1, Diepe Ondergrond, member.

Haak, H.W., International Association of Seismology and Physics of the Earth's Interior (IASPEI), member.

Haak, H.W., ORFEUS Board of Directors, member.

Haak, H.W., Technische Commissie Bodembeweging (Tcbb), member.

Haak, H.W., WG B of the CTBT, member.

Sleeman, R., European Seismological Commission (ESC), titular member.

Sleeman, R., European-Mediterranean Seismological Centre (EMSC), Dutch representative.

Sleeman, R., ORFEUS Working group 4, Seismological software, member.