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FINAL TECHNICAL REPORT

01 December 1984 - 30 November 1987

for project

DEVELOPMENT AND EVALUATION OF A REGIONAL SEISMIC ARRAY IN NORWAY

Edited by

Svein Mykkeltveit

Kjeller, 31 January 1988

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I. SUMMARY

This report gives an account of the work conducted by NORSAR in conjunction with development and evaluation of the NORESS regional array in Norway during the period 1 December 1984 - 30 November 1987 under Contract No. F49620-85-C-0016.

In order to maintain continuity in the quarterly technical reporting (which will continue under new contracts), this report also includes detailed technical reports for the period Oct-Dec 1987. Summaries are given for the last year of the 3-year contract, and for the entire contract period.

The purpose of the development of an experimental regional array in Norway has been to take advantage of the extremely good propagation of high-frequency energy for regional seismic phases in Eurasia. Since Norway is located within the same geologic plate boundary as the Soviet Union, the deployment of such an array in Norway provides important new insight with respect to the projected performance of possible future in-country stations in the U.S.S.R.

During the contract period, there have been some changes to the field installation that affected the array geometry. Before the end of the contract period, however, the initial NORESS geometry from 1984 was completely restored. In October 1985, an experimental high-frequency system was added to the NORESS configuration.

A few modifications to the field equipment have aimed at further improving the reliability of the system. Repairs have typically amounted to changing broken cards. Power outages at the field site have been the only significant factor contributing to field installation downtime. The average uptime for the field installation was 99.6% for the contract period. Altogether, the field installation has been operating very reliably in its unmanned mode throughout the three-year period.

The performance of the NORESS Earth Station for transmission of seismic data to the U.S. has also been very good during this 3-year period. The entire field system (comprising data acquisition system and satellite earth station) provided seismic data to the INTELSAT satellite during 99.2% of the time during these three years of operation of NORESS. The downtime of the ground station was mostly due to frequency checking and power failures. Other reasons (contributing only negligibly to the downtime) were scheduled maintenance and three instances of component failure in the satellite earth station.

The transmission of NORESS data via a 64 Kbits/s digital land line to the data processing center at Kjeller suffered from several technical problems during the period January 1985 - November 1986. We repeatedly approached NTA on the subject of the performance of this line, and NTA made some technical improvements to a critical part of the transmission path in October/November 1986. These modifications resulted in improved performance of the line. The yearly uptimes for this line were for 1985 87.2%, for 1986 89.4% and for 1987 99.0%.

All data transmitted to Kjeller have been subjected to real time processing using the RONAPP algorithm, and a total of 152,470 detections were declared during the reporting period. A seismic bulletin with the processing results has been transmitted regularly via the ARPANET to the Center for Seismic Studies in Rosslyn, Virginia, since May 19, 1985. All NORESS data recorded at Kjeller during this 3-year period have been permanently stored on magnetic tapes.

Equipment for use in the maintenance of the field installation and for the data acquisition and processing center at Kjeller has been purchased during the reporting period. All equipment purchased under this contract performs entirely satisfactorily.

Several investigations related to the NORESS array and its seismological capabilities have been carried out over the latest years.

These research efforts are, however, related to other contracts and the results are described in the appropriate contract reports. These studies have testified to the success of the NORESS project, and the results that have been obtained must be rated as very encouraging. In short, the NORESS array has been shown to provide a breakthrough in the detection and location of weak seismic events at regional distance.

The research program initiated with the installation and further development of the NORESS array, as reported on here, now continues under other contracts. After the installation in 1987 of a second regional array in Norway, the emphasis is now on the exploitation of regional arrays operated jointly in a network configuration.

II. GENERAL BACKGROUND

The purpose of the development of the regional NORESS array in Norway has been to take advantage of the extremely good propagation of high-frequency energy for regional seismic phases in Eurasia. Since Norway is located within the same geologic plate boundary as the Soviet Union, the deployment of such an array in Norway provides important new insight with respect to the projected performance of possible future in-country stations in the U.S.S.R.

The array was constructed in Norway as a joint enterprise between Sandia National Laboratories, Albuquerque, U.S., and NORSAR, and initial data from the array were available from September 1984. Seismic data are transmitted via satellite to several recipients in the U.S., and (from January 1985) via a 64 kbits/s digital land line to the NORSAR Data Processing Center at Kjeller.

Since 1979, NORSAR has conducted extensive field experiments to assess the potential of regional arrays in detection and location of regional seismic events. Results obtained from this work were utilized in the planning and design work for NORESS. Current and previous NORSAR research contracts with DARPA have contained several tasks that relate directly to the processing of data from regional arrays like NORESS. In particular, a processing package (RONAPP) for on-line detection and location of regional seismic events was developed and tested. The data from NORESS have been subjected to real-time processing using the RONAPP algorithm since data from NORESS became available at the NORSAR Data Processing Center in January 1985.

Under a FY84 contract, DARPA provided funds for the initial deployment of the NORESS array. This involved funds for site preparation work and also initial purchases for the data processing center at Kjeller.

Additional items for the data processing center have been acquired under the contract reported on here which also provided funds for further developments, refinements and evaluation of NORESS.

III. FIELD INSTALLATIONS

III.1 Modifications and changes, Oct-Dec 1987

No modifications or changes were made to the NORESS field installations during this period.

III.2 Maintenance and repair, Oct-Dec 1987

On a few occasions, it has been necessary to restart the high-frequency system manually following power outages.

An outage during October 16-19 was due to power failure following a severe storm. During the storm, numerous trees fell over the power line running out to the field site, and it took the electricity company several days to mend all damage.

III.3 Summary for the period 1 Dec 1986 - 30 Nov 1987

The only modification to the field system during this year was a modification to the high-frequency field system that was implemented in May, when a fiber optic data link was installed between the high-frequency unit and the interface for transmission of high-frequency data to Kjeller. This change was implemented in order to make the entire NORESS high-frequency system identical to the system that was installed in conjunction with the new northern Norway array (ARCESS) later on in 1987. This change did not affect the data format, and is thus not noticed by the data users.

A few component failures affected the array data, but typically, only one data channel was affected at a time. Details on such outages are given in the quarterly reports.

The power needed for the field installations is supplied commercially, and a battery bank at the field site provides backup during power

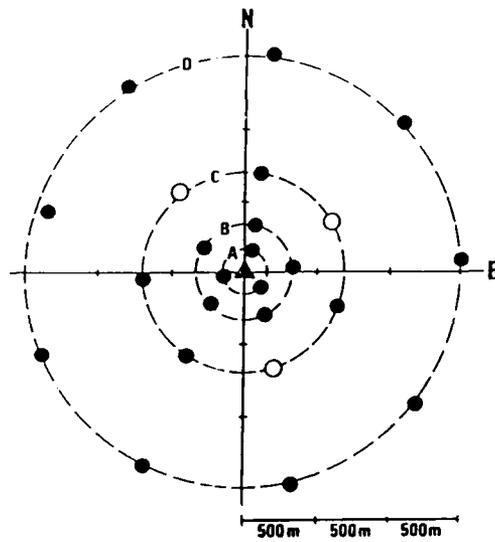
failures. The battery backup, however, is not sufficient for keeping the system alive during long power outages, which occurred particularly during October and November. These power outages (together with two instances of preventive maintenance work) affected the uptime of the field installation, such that NORESS data were provided to the communications links 98.8% of the time during the one-year period reported on here. The extended outage due to the storm in October (see Section III.2 above) contributed alone 64% of the field installation downtime for this year.

III.4 Summary for the contract period

The configuration of the NORESS array is shown in Fig. III.4.1. Originally, the array had vertical short-period sensors at all 25 sites, and in addition short-period sensors recording the north-south and east-west horizontal ground motions at C2, C4, C7 and at the center of the array (A0). All short-period seismometers were of type GS-13, placed in shallow vaults. At the center of the array, a borehole contains a broad-band seismometer of type KS-36000. The broad-band seismometer has remained unchanged in this position during the 3-year period.

In late September 1985, several modifications affecting the array geometry took place. After completion of these changes, the array had short-period vertical seismometers at all previous locations except A3, and now also in the borehole at the array center (F0), which is located 5 m away from the shallow vault at A0. Short-period 3-axis elements were then located at F0, A0, C4 and C7. The three-axis borehole seismometer deployed at F0 was of type S-3. The reason for these changes was to provide for a capability of comparing the new three-axis S3 borehole seismometer with the GS 13 three-axis station in the nearby shallow vault at A0.

On April 1, 1986, the original NORESS array geometry was nearly restored, with three-axis instruments at the array center and at sites



- LEGEND:
- VERTICAL SHORT PERIOD
 - 3-COMPONENT SHORT PERIOD
 - ▲ 3-COMPONENT BROAD BAND
AND 3-COMPONENT SHORT PERIOD

Fig. III.4.1. The geometry of the NORESS array. The short-period instrument at the center of the array is denoted A0.

C2, C4 and C7. The only deviation from the original geometry after this change was the siting of the three-axis instrument in the 60 m deep borehole at F0 instead of in the surface vault (A0) next to the borehole.

On September 24, 1986, the original NORESS configuration was completely restored, with CIDs 21, 61 and a1 now used for recording three-axis data from site A0 (surface vault) instead of F0 (60 m deep borehole).

From these experiments, it was determined that the S-3 borehole seismometer suffered from technical problems, and the S-3 instrument was pulled from the borehole and returned to the Sandia National Laboratories in Albuquerque later on in 1986. As of expiration date of this contract (30 Nov 1987), it has not been reinstalled in Norway.

In October 1985, an experimental high-frequency seismic element (HFSE) was added to the NORESS configuration. This is a system that takes the analog output from a 3-axis seismometer in NORESS (initially the borehole instrument at F0; later on from instruments at A0), digitizes the data at a rate of 125 Hz and utilizes a 24-bit analog-to-digital converter (in comparison, 16-bit A/D-converters are used for the NORESS data proper). The introduction of the HFSE system into NORESS did not affect the NORESS data itself; the HFSE data stream represents an added capability. Data from the HFSE system are formatted and sent via an SDLC protocol communication controller for subsequent transmission over a 19.2 Kbits/s segment of the 64 Kbits/s land line for transmission of data from NORESS to the data center at Kjeller.

The NORESS field installations were deployed during the fall of 1984. The first task after completing this work was to check the quality of the data received at Kjeller and at Sandia in Albuquerque. These checks revealed certain problems with the data quality, and during January-March 1985, a sequence of trouble-shooting on field hardware was carried out in close cooperation with Sandia, with the purpose of locating the sources of these errors in the data from the array. The

resulting modifications amounted to adding filters to the data channels. After these and some other minor modifications, the error rate associated with the field system itself has been extremely low.

In the initial phase of operation of the NORESS array, the array site was visited almost daily by our field technicians. Since the field system is highly modular, repairs typically amount to replacing cards that are identified to cause loss of data. The state-of-health data incorporated in the data stream from the array normally give exact indication of the origin of the problems, so that repair services can be effectively executed by the field technicians. After some component replacements at the beginning of 1985, the field system has become more and more reliable, and only occasional visits to the field site are needed. During the last two years, such component failures have occurred only 3-4 times per year.

Apart from a minor water leakage through the cable entrance pipe in the vault at B4, there have been no problems during the entire 3-year reporting period that could be associated with the site construction work of the summer of 1984.

Apart from a few instances of scheduled maintenance and component failures, the only reason for downtime of the NORESS field installation is power failure. The power is supplied on a commercial basis by the local electricity company, and there is a battery backup to handle short power outages. During the first year of NORESS operation, power breaks causing outage of the field installation were negligible, especially after the trouble-shooting period was completed. For the second year of operation, the corresponding downtime was approximately 10 hours, and for the final year of the contract the downtime was 95 hours. The main contributor to this relatively high value was the storm in October of 1987 (see paragraph III.2 above). Over the three-year period, the uptime of the field installation was then 99.6%. If it were important to improve this performance, it would be necessary to supply an independent power source that could also handle the long power outages for the commercially supplied power.

As an overall conclusion, we are, at the end of this three-year period, very pleased with the NORESS field installation. The field system is robust and reliable and presents few problems to our operations.

IV. DATA TRANSMISSION

IV.1 Satellite transmission of data to the U.S., Oct-Dec 1987

The satellite transmission of data to the U.S. from the NORESS field installation was interrupted eleven times, all due to power breaks. These outage periods are listed in Table IV.1.

16 Oct 1818	to	19 Oct 1422	due to power break
22 Oct 1415	to	1421	due to power break
24 Oct 1348	to	1415	due to power break
1 Nov 0701	to	1100	due to power break
13 Nov 0104	to	1038	due to power break
13 Nov 1235	to	1338	due to power break
13 Nov 1447	to	1514	due to power break
19 Nov 1141	to	1434	due to power break
22 Nov 0732	to	1747	due to power break
27 Nov 2322	to	2328	due to power break
2 Dec 2302	to	3 Dec 0103	due to power break

Table IV.1. Outage period for the NORESS satellite transmission system October 1987 - December 1987.

The total uptime for the NORESS Earth Station for satellite transmission of data to the U.S. was thus 97.7%. The major contributor to the downtime was the period 16-19 October. The power break during this interval was due to a severe storm, as reported on also in section III of this report.

On Oct 2, the TWTA gain of the NORESS satellite ground station was increased by 5 dB. This adjustment did not cause a downtime of the ground station.

IV.2 Land line to Kjeller, Oct-Dec 1987

The 64 Kbits/s transmission line from the NORESS array site to the data processing center at Kjeller failed on seven occasions, with a resulting total downtime of 13 hrs 28 mins during the reporting period. This implies that the total uptime for the transmission line was 99.39%.

IV.3 Summary for the period 1 Dec 1986 - 30 Nov 1987

Reasons for the outages and number and total length of outage periods of the satellite transmission of data to the U.S. were as follows:

Frequency checking and adjustment :	3 periods, total 1 hr 10 min
Power failure at field site :	25 periods, total 116 hrs 25 min
Control line failure :	1 period, 10 min

The frequency checks were initiated by requests from Intelsat. The total outage time during this one-year reporting period was 117 hrs 45 mins, which gives a total uptime for the satellite earth station of 98.66%. This is a degradation of performance relative to the previous year, and again, the main contributor was the power break due to the storm in October. We note that apart from these power breaks, the ground station has operated in an extremely reliable fashion, and the ground station itself has had no component failure whatsoever during this year.

NORESS data have been transmitted to the NORSAR data processing center at Kjeller via a 64 Kbits/s land line since it was put into operation in January 1985. Until November 1986 the quality and performance of this line was not satisfactory, and the Norwegian Telecommunications Administration made an effort in October and November of 1986 to improve the reliability of the line. The performance during the one-year reporting period shows that these modifications did result in a radical improvement of the transmission line uptime relative to

previous performance. The uptime of this land line for the one-year period reported on was 99.0%.

IV.4 Summary for the contract period

The NORESS Earth Station, located at the NORESS field installation, provides real-time satellite transmission of NORESS data to three recipients in the U.S.

A problem during the early phase of the earth station was lack of stability of the transmission frequency. This problem was solved in March of 1985, though the installation by COMSAT General of a new oscillator.

During the three-year reporting period 1985-1987, the reason for and number of outage periods for the satellite transmission of data were as follows:

	1985	1986	1987
Frequency checking and adjustment :	16	10	3
Equipment failure at ground station :	1	2	0
Scheduled maintenance :	5	2	0
Control lines failure :	5	0	1
Power outage at field site :	6	5	25

The lengths of individual outage periods ranged from 2 minutes to 68 hours. The yearly uptimes of the ground station were:

1985 :	99.2%
1986 :	99.8%
1987 :	98.7%

The degradation in 1987 is due to the many power failures this year. From the figures given above, we see that otherwise the operation of the ground station is gradually getting more stable and reliable: The number of frequency checks requested by Intelsat is decreasing; there were no equipment failures in 1987; there is no longer need for doing

maintenance that requires halting the transmission; and the control lines seldom fail (these lines allow the Norwegian Telecommunications Administration to remotely control the on/off switch of the transmitter, and NTA has required that if the control lines fail, the ground station should stop the transmission).

We take these figures to indicate that the NORESS ground station itself is operating extremely reliably, and with an independent power source, the annual loss of data due to ground station downtime could be reduced to a matter of minutes.

Transmission of NORESS data via a 64 Kbits/s land line to Kjeller started on January 2, 1985. This line is leased from the Norwegian Telecommunications Administration (NTA). We were initially not particularly pleased with the service offered by NTA. There were two main reasons for the unsatisfactory performance:

1. The lack of repair services by NTA during weekends and holidays
2. Technical problems with various components along the transmission paths.

We approached NTA requesting their actions on these problems, and work during October and November of 1986 took care of the technical problems. In addition, NTA has extended their repair service outside normal office hours, and we are currently generally satisfied with the quality of service from NTA regarding this land line. The annual uptimes of the land line have been as follows:

1985 :	87.2%
1986 :	89.4%
1987 :	99.0%

The figures dramatically reflect the performance improvement that resulted from solving the problems that prevailed in 1985 and 1986.

V. DATA CENTER OPERATIONS

V.1 Data recording, Oct-Dec 1987

The breaks in the NORESS recording task arising from problems at the Kjeller data center can be grouped as follows:

Number of breaks	Cause of break	Total downtime
1	Hardware failure	10 hrs 9 mins
1	Hardware service	11 mins
4	Power break	2 hrs 40 mins
1	Power break, modem	66 hrs 46 mins

Monthly uptimes for the NORESS online data recording task, taking into account all factors (field installations, transmission line, data center operation) affecting this task were as follows:

October : 87.6%
 November : 93.9%
 December : 91.0%

Fig. V.1.1 shows the uptime for the data recording task, or equivalently, the availability of NORESS data in our tape archive, on a day-by-day basis, for the reporting period.

V.2 Data processing and bulletin transfer, Oct-Dec 1987

The real time processing of NORESS data, using the RONAPP processing package, has continued during the reporting period. 13,485 detections were declared by the automatic processor during October - December.

The bulletin with the processing results has been transmitted daily to the Center for Seismic Studies in Rosslyn, Virginia, via the ARPANET.

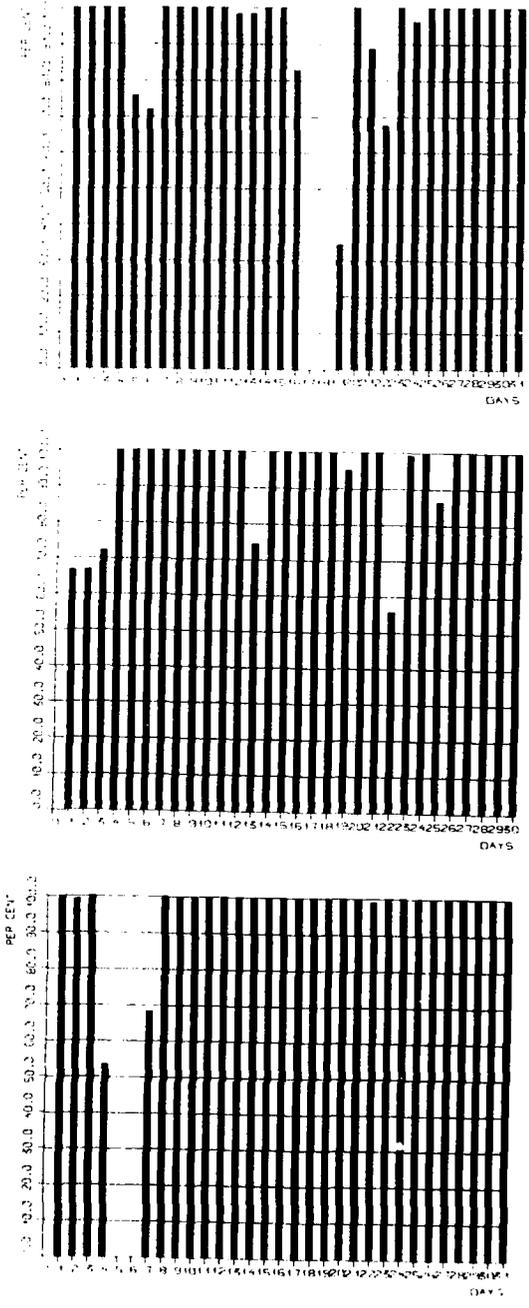


Fig. V.1.1. NORESS data recording uptime for October (top), November (middle) and December 1987 (bottom).

V.3 Summary for the period 1 Dec 1986 - 30 Nov 1987

During this one-year period, altogether 51,982 detections were declared by RONAPP for the NORESS data received and processed at Kjeller. There has been no change in the RONAPP beam deployment during the reporting period, which means that there has been a fixed beam deployment since 14 March 1985.

During the entire reporting period, a reviewed bulletin has been transmitted regularly to the Center for Seismic Studies in Rosslyn, Virginia, via the ARPANET.

All NORESS data recorded at Kjeller during the reporting period have been permanently stored on magnetic tapes.

The uptime of the data recording task was 97.5% for this one-year period.

V.4 Summary for the contract period

The monthly uptimes for the data recording task are shown in Figs. V.4.1, V.4.2 and V.4.3 for the years 1985, 1986 and 1987, respectively. These figures clearly illustrate the improvements following the modifications made to the transmission line in late 1986. The slight degradation of performance during late 1987 was mainly due to power breaks, as reported above.

The on-line processing of NORESS data using the RONAPP package started on January 2, 1985. Based on the experience from the first two months of data processing, certain parameters in the processing package controlling the detection and location of seismic events were modified on March 14, 1985. These parameters control among other things the number of beams deployed for the detection processing, the beamforming steering delays, bandpass filters applied and the detection threshold for each beam. This parameter setting has remained unchanged since the modification on March 14, 1985. The number of detections by this

UPTIME FOR ALL MNDS , NORESS - 1985 -

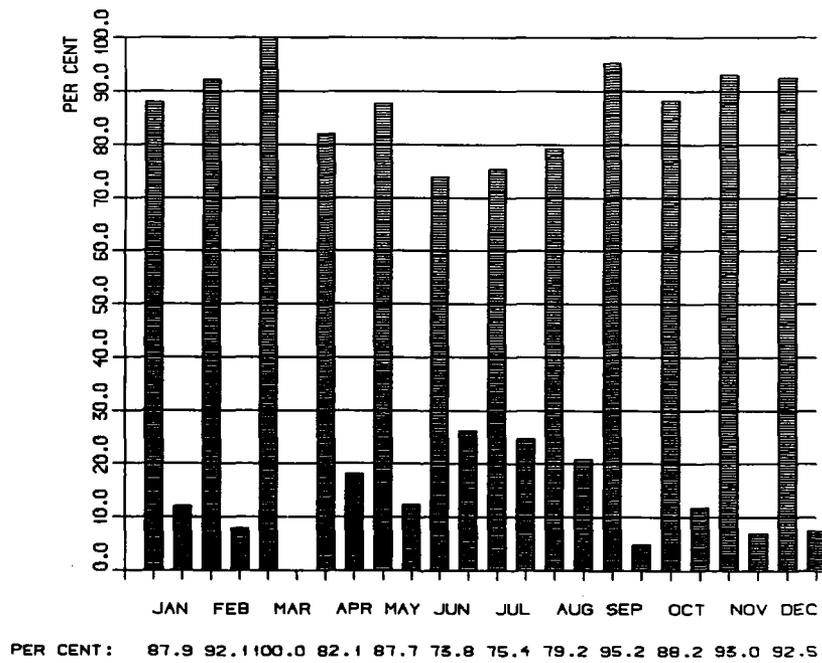


Fig. V.4.1. Monthly data recording uptimes for NORESS for 1985. (Tall bars represent uptime, short bars represent downtime.)

UPTIME FOR ALL MINDS , NORESS - 1986 -

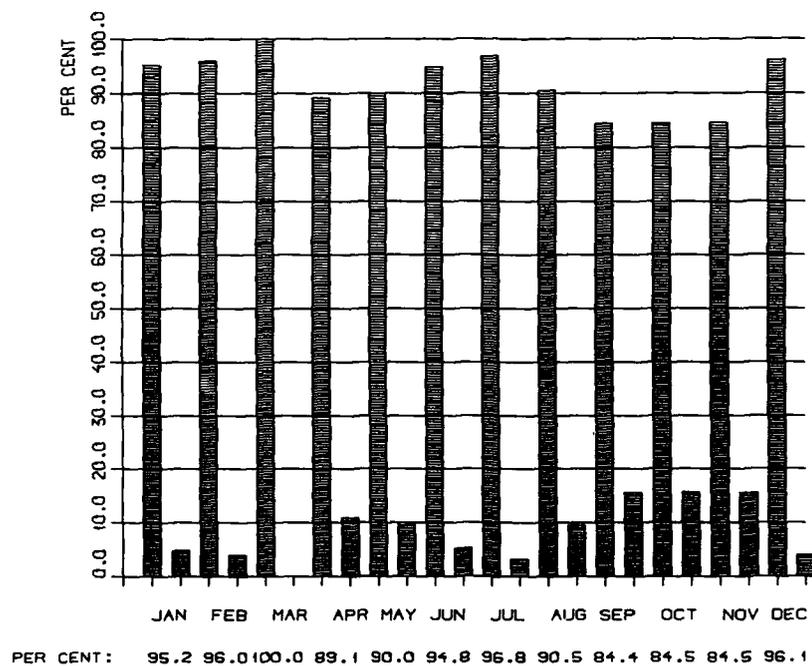


Fig. V.4.2. Monthly data recording uptimes for NORESS for 1986.

UPTIME FOR ALL MNDS , NORESS - 1987 -

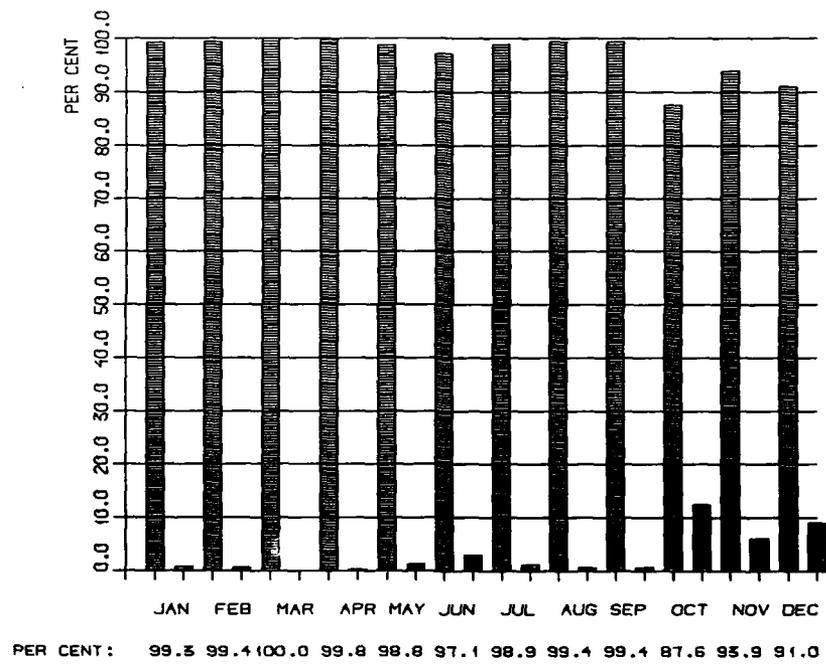


Fig. V.4.3. Monthly data recording uptimes for NORESS for 1987.

package has been 152,470 for the period 2 January 1985 - 30 November 1987.

Since May 19, 1985, a seismic bulletin with the processing results based on the real time event detection with the RONAPP package has been transmitted to the Center for Seismic Studies in Rosslyn, Virginia, via the ARPANET. Since October 20, 1985, this bulletin is reviewed by an analyst before being transmitted.

All NORESS data recorded at the Kjeller data center during the 3-year reporting period have been permanently stored on magnetic tapes.

VI. EQUIPMENT PURCHASED

A substantial amount of equipment, for research and further development of the NORESS array and the associated data processing, has been purchased under this contract.

The following equipment, for use in conjunction with the field installation, has been purchased during the three-year reporting period:

- Spectrum analyzer
- Miniscope, battery
- Logic analyzer
- Protocol analyzer
- Oscilloscope
- Paper recorder
- Frequency counter
- Digital voltmeter
- Radio telephones, 2
- Backhoe
- PCM 8-channel acquisition and transmission system
- Video camera and playback unit
- Interface cards for protocol analyzer
- Telecopier
- Trailer for backhoe

The following equipment for the data acquisition and processing center at Kjeller has been purchased during the 3-year reporting period:

- Disk, 4*590 Mbytes
- Storage controller
- Computer upgrade
- Tape drives, 2
- Graphic color terminals, 4
- High resolution color graphics work station
- Upgrade of 3274 controller
- Vector-to-raster converter
- 22" raster plotter
- IBM XT/370
- Printer
- Alarm unit
- Video screens, 3
- Control panel, etc.
- Terminal for line testing
- Tape unit for line testing

IBM/XT

Array processor, IBM 4381
Take-up spool for Versatec raster plotter
Raster interface for Versatec plotter
Channel-to-channel adapter
Halon 1301, fire extinguishing system
IBM 7170 control unit
Optical disk with interface
Laser printer with graphics
Microprocessor with A/D converter, communication
and peripherals

All equipment listed above has been essential to the NORESS developments. The equipment has contributed towards ensuring stable operation and has made it possible to exploit the capabilities of the array. All equipment has performed satisfactorily.

VII. SPECIAL REPORTS AND DOCUMENTATION RELATED TO NORESS DATA

VII.1 NORESS online system

A comprehensive report entitled "NORESS online system" and dated April 1986 was prepared by Rune Paulsen. This report, comprising 152 pages, gives a factual description of the NORESS data processing center at Kjeller, with its hardware and software components. The emphasis is on the data acquisition task, data base design, data center operation, system monitoring, and data formats. The report also summarizes system operational experience. Details of the real time processing of NORESS data are not given in this report.

The report is available from NORSAR upon request.

VII.2 Other reports related to analysis of NORESS data

NORSAR's basic research contract with DARPA (monitored by AFTAC) includes items like comprehensive evaluation of the capabilities of the NORESS array as well as the use of NORESS data in seismological verification research. Our semiannual technical summaries submitted under the AFTAC contract contain numerous contributions that make use of NORESS data to address questions of central importance in our research program. We refer the interested reader to these semiannual technical summaries, which can be obtained from NORSAR upon request.

NORESS data have also been used extensively in research programs conducted at other institutions, particularly in the U.S., where both university and industrial contractors have been working with analysis of NORESS data. Results are documented in appropriate contract reports, as well as in journal papers.

VIII. PERSPECTIVES FOR THE FUTURE

Numerous studies over the past three years have testified to the success of the NORESS project. The research results that have emerged from our program and the programs at other institutions have been very encouraging, as the array has proved capable of taking advantage of the very efficient propagation of high-frequency seismic phases in Eurasia to provide a breakthrough in detection and location of very small underground explosions and other seismic sources at regional distance (0-2000 km).

In order to assess the full and eventual capabilities of the new NORESS concept, it is necessary to conduct research on how several such arrays can be employed together and operated interactively, using the data in a simultaneous processing scheme. Accordingly, in 1986 NORSAR submitted to DARPA a proposal for expanding the NORESS experiment to include a second regional array in Fennoscandia. This new regional array termed ARCESS (Arctic Experimental Seismic Array System) is situated in northern Norway, at a distance of about 1100 km from NORESS. The ARCESS installation was completed in the fall of 1987, under a separate contract monitored by AFOSR.

An ambitious research effort is now under way in the U.S. to develop a knowledge-based system ("expert system") capable of processing data from several regional arrays. NORSAR is involved in the development of this system which is termed the Intelligent Array System (IAS), through direct participation by its own staff. The initial version of IAS is expected to be delivered to NORSAR in 1989.

A FY88 contract monitored by AFTAC is now in place, that provides for the continued operation and further development of the NORESS and ARCESS arrays, as well as NORSAR's participation in the IAS development.