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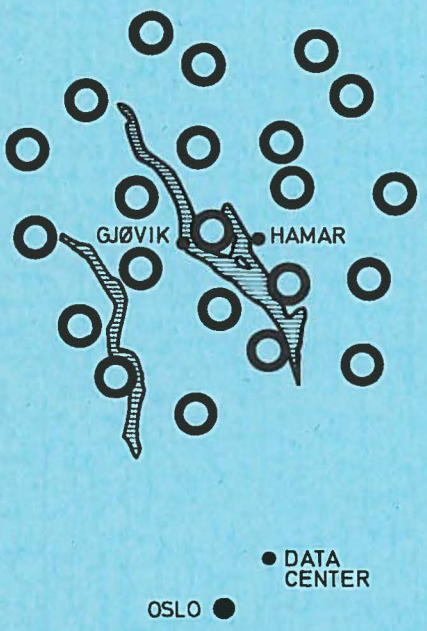
PROGRESS REPORT
NORSAR PHASE 3

4th Quarter 1971



NORWEGIAN SEISMIC ARRAY

NORSAR

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NTNF/NORSAR
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NORSAR Report No. 20
Budget Bureau No.22-R0293

PROGRESS REPORT
NORSAR PHASE 3

4th Quarter 1971

prepared by

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Status per 31 December 1971

The NORSAR project has been sponsored by the United States of America under the overall direction of the Advanced Research Projects Agency and the Technical Management of the Electronic Systems Division, Air Force Systems Command.

ARPA Order No. 800 Program Code No.IF10

Name of Contractor	:	Royal Norwegian Council for Scientific and Industrial Research
Date of Contract	:	May 15, 1970
Amount of Contract	:	$ 1.300.883,-
Contract No	:	F19628-70-C-0283
Contract Termination Date	:	June 30, 1972
Project Supervisor	:	Robert Major, NTNF
Project Manager	:	Per Tveitane (temporary)
Title of Contract	:	Norwegian Seismic Array (NORSAR) Phase 3

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I SUMMARY

The report covers the period 1 October - 31 December, 1971, which is characterized by software debugging, system improvements and evaluation, and seismological research. The most important single event was the NTNF/NORSAR arrangement of a seminar on Seismology and Seismic Arrays in Oslo, November 22 - 25, 1971.

Monitoring and calibration of the field instrumentation are performed regularly, and the stability of the SP seismometers are improving. The array was operated on a contineous basis, and only 44 hours of data was lost in the period, half of which was due to hardware maintenance. The Event Processor threshold was increased from 12 to 13 dB, reducing the EP computer time load by ca 30%. The NTNF/NORSAR staff presented 5 papers at the above-mentioned seminar.

II ADMINISTRATION AND ECONOMY

The contract between ARPA and NTNF for NORSAR operation expires June 30, 1972. A detailed cost proposal for contract extension to June 30, 1973 has been completed "It is assumed in the proposal that the present operating mode with only minor modifications will be retained. During the reporting period the data center computer equipment maintenance contract was signed with IBM/Norway." Moreover, new procedures for property control have been established. The main changes are concerned with spare parts and instrument test equipment.

Expenditures in the period 1 October - 31 December 1971

1.	Operation & Maintenance		
	1.1 Data Processing Center	$ 78 695	
	1.2 Field Installations	$ 68 108	
	1.3 Data Communication	$ 10 966	$ 157 769
2.	Research & Development		$ 12 189
3.	Administration & Support		$ 15 734
		TOTAL	$ 185 692

III ARRAY MONITORING AND CONTROL - FIELD MAINTENANCE

The array field maintenance was until September 30, 1971 contracted to the company NORATOM-NORCONTROL A/S, but from that date onwards the responsibilities for this work rests with NTNF/NORSAR. Eight out of the group of 10 maintenance technicians remained in their positions, i.e. transferred to the NTNF/NORSAR staff.

Array Monitoring

Refinement of existing procedure and development of new routines for remote monitoring of the array instrumentation continued in the reporting period. Computer programs for LP seismometer calibration and off-line LP channel performance evaluation were implemented during October and November.

Array Maintenance

Calibration of SP seismometers concerning natural frequency (NF) and damping ratio (DR) became the main task in the reporting period. Instruments having a response outside specified tolerance limits were removed and then checked in the maintenance center. Since the seismometers exhibit individual trends in the NF-fluctuation as a function of temperature, each instrument was specially tested for establishing the individual natural frequency setting before reinstallation in the boreholes. Despite this precaution, the construction of the SP seismometers creates many problems of controlling their response during the installation phase, so this task has become a time consuming project. At 2 October 25 instruments were

outside specified tolerance limits in natural frequency (0.9 - 1.1 sec) and 44 sensors in damping ratio (0.65 - 0.70), while at the end of the reporting period 16 and 30 seismometers were outside the specified NF and DR limits respectively.

A new operating plan* for NORSAR array monitoring and control has been established. The most important tests and controls performed on a regularly basis, are tabulated below.

Table 1. NORSAR array monitoring schedules

Monitoring frequency	Test and control types
Daily	Control of array and communication system status based on recorded signals.
Weekly	Complete communication system checks of telephone lines and modems.
Biweekly	Calibration of all LP sensors, testing of SLEM performance, SP and LP channel gains.
Monthly	Detailed broad band and single frequency analyses performed on SP and LP data channels.

* O. Steinert: NORSAR AM Operating Plan, NORSAR Tech. Rep. Dec 10, 1971.

Finally, it should be noted that the performance of the array field instrumentation has been very good and characterized by a large degree of stability of the data channels.

IV COMPUTER CENTER OPERATION - DATA PROCESSING

The Detection Processor (DP) was recording data on-line for approximately 97% of real time in October and November, and 99% in December. Total down time for DP was thus 44 hours in the reporting period, half of which was due to hardware maintenance.

The on-line system encountered about 20 error stops in the period, with tape drive malfunction as the most significant factor causing problems.

A method for reducing the possibility of false detections caused by reactivation of transmission lines after communication outages was developed and implemented on-line 16 November. At the same date, recording of NORSAR LP and transatlantic data on a Low Rate tape became part of the on-line system and the DP threshold was changed from 10 to 10.5 dB. Minor modifications of NORSAR array beam deployment (array beam set 401) was implemented 14 December.

Programming Efforts

Most of the programming work in the period was related to the on-line DP, as described in the preceding paragraph. Several corrections were also made in the Event Processing system, and an increased flexibility was added to the

editing of seismic bulletins. The Data Retention programs were refined in order to reduce possible operator errors, and are now considered to work satisfactorily. A routine for displaying the Low Rate tape in an off-line mode on the Experimental Operations Console was completed. Moreover, work has started on implementation of incoherent beamforming on an experimental basis in the DP on-line system.

A number of the programming problems encountered in the reporting period were solved in cooperation with the IBM (Federal System Division, USA) group at NORSAR DPC.

Routine Event Processing

During the reporting period, considerable efforts have been invested in debugging and improving certain portions of the Event Processor (EP). The main changes have been the following:

- The band pass filter used in EP processing was changed from 0.9 - 3.5 Hz to 1.2 - 3.2 Hz on December 7, and to 1.0 - 3.0 Hz on December 22. Although the signal-to-noise ratio (SNR) increases with frequency (peaks between 1.5 - 3.0 Hz), the improvement in EP performance is modest. The reason is that the EP solution is unreliable for weak events which are not observable on the subarray beam level.
- The EP threshold was changed from 12 to 13 dB on November 11, as necessiated by computer time requirements for research and development work. The above resetting of the threshold reduced the EP computer

time allocation by 30% while the number of reported events decreased by 12%. In short, below a certain threshold the number of false alarms and events too small to be processed satisfactorily by EP, increases rapidly.

Some of the above results were obtained by a throurough analysis* of one month of EP data, in which analyst decisions were included. For example, average EP computer time per event was 9 min and 2.9 sec. The signal correlation and focal depth estimation portion of the event processor required 53% and 12% of the EP-time respectively.

At the end of the reporting period the Event Processor is considered to function satisfactorily, and further efforts will be concentrated on system improvements and more flexible parameterization of signal characteristics. A new and more reliable set of beam steering corrections and location calibration vectors are scheduled for implementation in January 1972.

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* H. Bungum & K. A. Berteussen: NORSAR Event Processor Computer Time Requirement, NORSAR Tech. Rep. No. 21, Dec 1971.

V RESEARCH AND DEVELOPMENT

Research and development in the reporting period have been focused on improvements of the software systems, array evaluation and seismological research as in the 3rd quarter of 1971. Some of this work was presented at the seminar on Seismology and Seismic Arrays in Oslo, November 22 - 25, 1971. More details on this arrangement are given in the next section and in Appendix I.

It is considered properly to summarize our research work by giving the title and abstract of relevant papers presented at the above seminar which are:

H. Bungum and K. A. Berteussen: Initial evaluation results from NORSAR.

Abstract:

NORSAR has now operated on a fairly regular basis since April 1971. Since May 1, the Event Processor output has been reviewed and edited by analysts on a daily basis. An average of 11 events have been reported per day, out of which 7.5 have been located, 4.5 between 30° and 90°. The 90% interval detectability in this range is about 4.2, and the 90% comulative detectability about 4.0, which is about 0.3 magnitude units less than the presently known figures for LASA. This difference in detectability can be explained by the difference in seismic background noise.

Data from May and June 1971 has been compared with results from NOAA. Roughly the same number of events have been reported by the two institutions, about half of which are the same events. The NORSAR location errors are in this initial phase about 330 km at a 50% level, and in the 30° - 90° range 50% of the

locations are within 240 km of the NOAA solutions. This will improve with the experience of the analysts and with future improvements in location calibration (removal of biased errors). The events not reported by NOAA are mostly located in the Alpide belt, in Central Asia and in the Western half of the Circum-Pacific belt.

E. S. Husebye, H. Gjøystdal and D. Rieber-Mohn:
Estimating array location capabilities.

Abstract:
An integrated part of the routine analysis of signals recorded by large seismic arrays is determinations of the corresponding epicenters. We have simulated the array event location process, and thus generated epicenter confidence ellipses, assuming that the observational errors in the basic wave parameters arrival time, azimuth and velocity are Gaussian. The above analysis was restricted to hypothetic data from one and two arrays. In the latter case we considered joint epicenter locations by LASA and NORSAR.

Structural inhomogeneities, especially in the site and source regions, cause biased errors in the observed arrival times across an array. Using travel time observations of ca. 130 NORSAR events, we have computed a model for time anomalies for the individual subarrays. Based on the latter results and Herrins tables, we simulated the NORSAR epicenter locations for the above 130 events and a reasonable agreement was obtained in many seismic regions.

E. S. Husebye, I. Noponen and D. Rieber-Mohn:
Signal spectra at NORSAR.

Abstract:

The basic tool in our analysis is the Fast Fourier Transform algorithm for generating amplitude and power spectra. Working with short periodic P-waves many types of spectra may be defined in order to simulate and evaluate the fundamental processing operations of an array. Our starting point is the Fourier Transform Smn(f) of the P-signal at M'th sensor of the n'th subarray. The initial data preparation includes a proper line-up of incoming waves and tapering. 10 sec transform window is used and several options for smoothing in the frequency domain are available. The spectral parameters considered so far are the arithmetic mean power or spectraform at frequency f of M sensors from N subarrays, and the power on a beam formed from M sensors in N subarrays. Other parameters of interest is the ratio between the above two spectral definitions, and the signal-to-noise ratio (SNR).

We have analyzed a number of events in the Nevada and Kazakh test site areas, and the preliminary results are as follows: NORSAR power spectra in general peak between 1 - 3 Hz and the corresponding SNR interval is 2 - 4 Hz. During subarray beamforming a signal loss between 1 - 4 dB for the frequency band 1 - 5 Hz has been observed, while the corresponding loss values for the array beam are 2 - 12 dB. The above results indicate that beamforming is not necessarily the best method for array detection of weak, high-frequency signals.

J. Filson and H. Bungum: Initial long period results at NORSAR.

Abstract:

Initial long period results, with an emphasis on the problems of discrimination and detection are presented. Group velocity measurements of events from central Asia show a minimum velocity of 2.9 km/sec near 16 - 18 seconds, however, power spectrum maxima range from 30 - 15 seconds depending on distance and source types. Frequency-wave number analyses on large reference events have been used to yield the appropriate velocity and azimuth for beamforming in searching for smaller events. Signal enhancement and deterioration as a function of frequency due to beamforming are discussed. On a limited population; the $m_b - M_s$ criteria separates source-types down to a single channel threshold of $M_s = 3.2$ at 40^o.

D. Doornbos and E. S. Husebye: Array processing of core phases and their precursors.

Abstract:

A relatively large freedom still exists in the construction of core models from seismic measurements, which is largely due to the observation and interpretation of small amplitude waves, preceding the phases predicted by the standard Jeffreys core model. Array processing techniques, suitable for the resolution in slowness and time of core phases and their precursors are discussed, in particular the usefulness and limitations of the Vespa process in this connection.

Data of half a year of NORSAR operation are used to constraint current core models. This is illustrated by means of various representative examples of interpretation of the precursors. The data used are of the type PKP and, where advantageous, combined with SKP. The Vespa process reveals to some extent the more complicated character of the precursors with $\Delta > 136^{o}$ and also of the refractions and reflections at the inner core boundary. Possible interpretations of these observations are discussed.

The above papers will be published in a booklet, Proceedings of the Seminar on Seismology and Seismic Arrays, Oslo, November 22 - 25, 1971. As far as we know, other participants in the meeting are in favour of such a publication, i.e. contribute with papers on the talks given.

VI MISCELLANEOUS

NTNF/NORSAR arranged a seminar on Seismology and Seismic Arrays in Oslo, November 22 - 25, 1971. A total of 69 scientists from 12 countries - 18 from North America, 32 from Europe, and 19 from Norway including 8 from NTNF/NORSAR - attended the meeting and altogether 28 talks were given. In Appendix I the seminar program and greetings from the European Seismological Commission are given.

Visitors to NORSAR Data Processing Center, Kjeller during the reporting period, were:

I. P. Basilow, Moscow Univ., Moscow, USSR
Nov 25 - 29, 1971

W. Dean, Geotech/SAAC, Alexandria, Va, USA
Nov 25 - 26, 1971

C. Felix, IBM/SAAC, Alexandria, Va, USA
Nov 25 - Dec 3, 1971

L. Gilbert, IBM/SAAC, Alexandria, Va, USA
Nov 25 - 26, 1971

T. Harley, Texas Instr./SAAC, Alexandria, Va, USA
Nov 25 - 26, 1971

J. Hjelmø, Geodætisk Inst., Copenhagen, Denmark
Nov 26, 1971

E. Hjortenberg, Geodætisk Inst., Copenhagen, Denmark
Nov 17 - Dec 1, 1971

I. Noponen, Helsinki Univ., Helsinki, Finland
Oct 1 - Dec 17, 1971

I. P. Passechnik, Moscow Univ., Moscow, USSR
Nov 25 - 29, 1971

S. Pirhonen, Helsinki Univ., Helsinki, Finland
Nov 9 - Dec 12, 1971

In the reporting period 94 data tapes were sent to SAAC, 2 tapes to Dr Doornbos, Utrecht, Netherlands, 1 tape to Dr Wieland, Karlsruhe, Germany, 2 tapes to Dr Hjortenberg, Copenhagen, Denmark, 2 tapes to Dr Filson, Cambridge, Mass., 3 tapes to Dr Pirhonen, Helsinki, Finland.

APPENDIX I

PROGRAM
for the seminar on
SEISMOLOGY AND SEISMIC ARRAYS
Lysebu, Oslo, Nov 22 - 25, 1971

Monday, Nov 22

0915 Bus departure from Lysebu

1030 Visit to NORSAR Data Processing Center, Kjeller.
R. Major, Director, Royal Norwegian Council for Scientific and Industrial Research (NTNF): Welcoming address.

P. Tveitane, NORSAR Project Manager:
A short Introduction to NORSAR.

E. S. Husebye, NORSAR Chief Seismologist:
Seismic Research at NORSAR.

Prof. I. Passechnik: Greetings from the European Seismological Commission.

A short movie about NORSAR.

1130 Lunch.

1200 Exhibition about NORSAR
Guided tour to the computer hall
Demonstration of the daily analysis work.

1430 Bus departure for Lysebu.

1815 Bus departure from Lysebu.

1900 Dinner at the Henie Onstad Art Center. Sponsored by NTNF.
After dinner there will be a guided tour to a special collection of modern art.

Tuesday, Nov 23

0900 Opening Address by Prof. M. A. Sellevoll, Chairman of the NORSAR Board.

Session I. Chairman: D. Davies

0920 K. Whitham: An Assessment of the Present Capability for Detection Location and Identification of Underground Nuclear Explosions. (Invited paper).

U. Ericsson: Yield-independent m(M) Discriminants from Networks.

D. Davies: The Discrimination Problem.

Coffee break

A.W.E. Jacob & P.L. Willmore: Teleseismic Observations of a 10-ton Explosion.

F. M. Anglin: Short Period Discrimination Studies using the Yellowknife Seismological Array Data.

H. Israelsson: Seismic Identification on Hagfors Data.

1230 Lunch

Session II. Chairman: U. Ericsson

1400 O. Dahlman: One Use of Array Stations.

E. S. Husebye, I. Noponen and D. Rieber-Mohn: Signal Spectra at NORSAR.

D. Doornbos & E. S. Husebye: Array Processing of Core Phases and their Precursors.

J. Filson & H. Bungum: Initial Long Period Results at NORSAR.

Coffee break

H. Bungum & K. A. Berteussen: Initial Evaluation Results from NORSAR.

C. P. Felix & W. L. Gilbert: Preliminary Results from the NORSAR System.

T. W. Harley: Preliminary Results on NORSAR Evaluation Program.

W. C. Dean: A Preliminary Evaluation of the LASA/SAAC System.

Wednesday, Nov 24

Session III. Chairman: S. Müeller

0900 I. P. Passechnik: Some Methods of Interpretation Seismic Array Station Data. (Invited paper).

I. Capon: Analysis of Microseismic Noise at the Norwegian Seismic Array. (Read by R. T. Lacoss).

M. Bossolasco, G. Gicconi & C. Eva: A Seismic Array in North-West Italy. (Read by S. Mueller).

Coffee break

P. Mechler: Structure of a Velocity Discontinuity Around 600 km Depth - Example Beneath France -.

I. Noponen: Event Location Errors using Arrays in Scandinavia.

R. M. Sheppared: Array Epicenter Mislocation Errors and their Probable Causes. (Read by D. Davies).

1230 Lunch

Session IV. Chairman: R. T. Lacoss

1400 M. Båth: A World-Wide Network of Array Stations - A Seismological Experiment. (Read by E. S. Husebye).

J. Hjelme: Writing Bulletins

D. Davies: Some Uses of Large Arrays

E. Rygg: Application of Dispersive Filters for SNR Gain.

Coffee break

E. S. Husebye, H. Gjøystdal & D. Rieber-Mohn: Estimating Array Location Capabilities.

J. Filson & C. Frasier: Source Studies Using Multiple Arrays.

U. Ericsson: The Evaluation of Discriminant Effectiveness.

R. T. Lacoss: Seismic Event Detection and Discrimination - Some Statistical Considerations.

Evening: Special meeting of the "Working Group on 10-ton Explosions".

Conveyer: P. L. Willmore.

Thursday, Nov 25

0900 Panel Discussion: Capabilities of Seismic Arrays; introduction by E. S. Husebye.
(On the panel: D. Davies, E. S. Husebye and R. T. Lacoss).

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

Association de Séismologie et de Physique de l'Intérieur de la Terre

COMMISSION SÉISMOLOGIQUE EUROPÉENNE

Moscow, Novembre 15, 1971

Dear Colleagues,

European Seismological Commission would like to pass its congratulations to all participants of the Opening Ceremony of NORSAR and the Organizing Committee on occasion of such significant event as opening of NORSAR which is of great importance for the development of seismological investigations in European countries ,especially, for the investigations of deep Earth's structure in Europe and to wish much success in scientific investigations. These investigations will be undoubtly promoted by valuable experimental data of NORSAR stations.

European Seismological Commission greets with satisfaction good initiation of Norway who has became a leader in European continent in the business of equipment of seismological science by new observational means.

E. Savarensky

Professor E.F. Savarensky,

ESC President