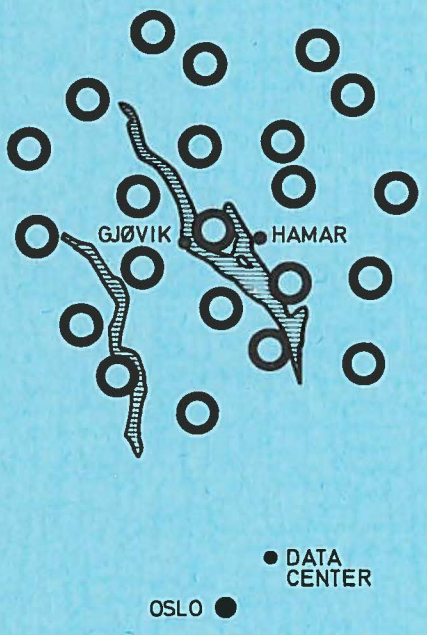
Royal Norwegian Council for Scientific and Industrial Research

PROGRESS REPORT
NORSAR PHASE 3

2nd Quarter 1972




NORWEGIAN SEISMIC ARRAY

# NORSAR

P. O. Box 51. 2007 Kjeller – Norway

NTNF/NORSAR
P.O. Box 51
2007 Kjeller
Norway

NORSAR Report No. 34
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# PROGRESS REPORT
# NORSAR PHASE 3

2nd Quarter 1972

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Status per 30 June 1972

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 | : | $ 2.051.886,- |
| Contract No | : | F-19628-70-C-0283 |
| Contract Termination Date | : | 30 June 1973 |
| Project Supervisor | : | Robert Major, NTNF |
| Project Manager | : | Nils Marås |
| Title of Contract | : | Norwegian Seismic Array (NORSAR) Phase 3 |

CONTENTS

## I SUMMARY

The report covers the period 1 April - 30 June 1972, which is characterized by implementation of incoherent beamforming in the Detection Processor and research aimed at improving and simulating the array detection capability. The present contract between NTNF and ESD for NORSAR operation was to be terminated 30 June 1972, but has been extended, including minor modifications, to 30 June 1973. The stability of the field equipment has been satisfactory in the reporting period. On-line data transmission from SAAC to NDPC via the trans-Atlantic link was implemented 24 April 1972. Recent modifications of the Event Processor have significantly reduced the computer time required for routine event analysis. A small multiarray experiment indicates that multiarray data processing is possible by replacing the signals with their envelopes.

## II ADMINISTRATION AND ECONOMY

The contract betwen NTNF and ESD for NORSAR operation originally covered the period 1 July 1970 - 30 June 1972. This contract has been extended to 30 June 1973 and the necessary modifications are included in Contract Amendment No. 4. Subcontracts for required external services for the period 1 July 1972 - 30 June 1973 have been negotiated with Norwegian Telegraph Administration (data communication lines), Regnesenteret Blindern-Kjeller (NDPC housing facilities) and IBM/Norway (computer hardware service). The latter two subcontracts have been submitted to ACO for approval. It is worth mentioning that the NTNF/NORSAR staff plan to be responsible for maintenance of data communication modems, thus resulting in an annual net saving of $12,300.- as compared to the previous contracting period.

Expenditures in the period 1 April - 30 June 1972

| | | | |
|---|---|---|---|
| 1. | Operation & Maintenance | | |
| | 1.1 Data Processing Center | $ 86 723 | |
| | 1.2 Field Installations | $ 27 879 | |
| | 1.3 Data Communication | $ 14 055 | $ 128 657 |
| 2. | Research & Development | | $ 14 983 |
| 3. | Administration & Support | | $ 17 250 |
| | | Total | $ 160 892 |

## III ARRAY MONITORING AND FIELD MAINTENANCE

The stability of the field equipment has been satisfactory in the reporting period. Only in a few cases have the acquired seismic data been degraded by discovered malfunctions. On 9 September 1971 the 01C NS and EW LP seismometers were place in interchanged position. This situation was corrected 19 June 1972. With the exception of a number of cable breaks affecting the subarrays 01A, 06B, 01C, 03C and 14C, the quality of the communication lines has been stable.

### Array Monitoring (AM)

Further corrections to the AM computer programs, based on an investigation of the AM system performed in cooperation with IBM, Federal Systems Division, have been accomplished. The problem of large discrepancies between calculated and field measured values for the LP sensor damping have been solved and is explained in terms of the circuit impedance when the Ithaco amplifier is/is not connected. The AM programs will be modified to take this parameter into account.

The routine monitoring has been troubled by a large number of program interruptions, which to a large extent can be explained by software sensitivity to hardware

troubles in the field like signal generator malfunctioning, etc. However, further research is necessary for eliminating this kind of problems.

Development of new computer programs for remote monitoring of CTV battery charging and modification of present AM programs to take advantage of previous AM results are in progress.

Array Maintenance

New tolerances for SP sensor damping and natural frequency were introduced 10 April 1971 and are set to 0.60 - 0.80 Hz and 0.85 - 1.15 Hz respectively. Number of sensors outside these tolerance limits are 7 as of 30 June 1972.

Several lightning protection cards were damaged during the last half of June, resulting in low channel gains. This problem was caused by heavy thunderstorm activity in the array siting area during this period. With the exception of a faulty SLEM power unit and a rectifier, the disclosed instrument malfunctions have all been easily corrected. A faulty seismic cable at sensor SP 04, 01C resulted in a serious degradation of the DP performance in the interval 9-12 June.

A preventive maintenance program to control field construction details, such as the physical state of the vaults' interior and exterior, and to accomplish minor instrument modifications, was started this spring and is expected to be completed in the fall.

Communication

The quality of the communication lines has been very satisfactory with no deteriorating performance as compared to previous periods. The present manual routines for monitoring the performance of the lines are time-consuming and will be computerized. Programs for statistical analysis of communication data are in progress.

## IV COMPUTER CENTER OPERATION - DATA PROCESSING

### Detection Processing

The Detection Processor (DP) was recording data on-line for approximately 98% of real time in April and 99% in May and June. Total down time was thus 32 hours in the second quarter of 1972, most of which is attributed to minor hardware failures.

On-line data transmission from SAAC to NDPC (shortened to TAL) as previously agreed upon was implemented 24 April. Periodic error reports for the TAL transmission SAAC to NDPC have been generated by DP since 1 June. These statistics show that the number of TAL records received at NDPC per hour is systematically 2-3% lower than the expected number of 3600, i.e., one record per second. The cause of this problem is believed to be a certain feature within the SPS data adapter (namely the insertion of extra 'DLE' characters, ISRSPS REF 103, ch 5-6-1). The problem may be solved either by hardware changes both at SAAC and NDPC or by reduction of the transmitted record length which is presently 299 bytes per second.

### Programming Efforts

The programming work in the second quarter was focused upon implementation of the TAL transmission system and continued work on the incoherent beamforming detector. By the end of this quarter, the new detector had been successfully tested, and it is expected to be implemented on-line during July.

A few program changes were performed within DP and EP. Among those was a modification of the EP beampacking procedure to improve epicenter accuracy by this method, similar to what had previously been implemented at SAAC.

A capability to perform plotting from the on-line DP was implemented 19 June. When a second plotter is acquired at NDPC in the near future, an option will then be available for operating both plotters in parallel.

Parts of the programming work in the reporting period were performed in cooperation with the IBM (FSD) personnel, who left NORSAR data center 30 June 1972 due to contract termination.

Routine Event Processing

As mentioned in the previous Progress Report, the filter and beam deployment changes in the Event Processor (EP) had a positive effect on the NORSAR event detection performance. The EP-threshold has been made an initialization parameter, thus facilitating threshold changes. The reason for this is that the false alarm rate varies considerably with background noise level and therefore, a relatively constant "EP analyst rejection rate" requires a floating EP-threshold. In the reporting period, the threshold has been in the range 3.4-3.8. It should also be noted that a significant reduction in EP computer time required per event processed has resulted from several modifications of the EP package. For example, the EP computer time per event was in average around 9 min in Oct/Nov 1971 as compared to about 3.5 min in May 1972. The latter figure is based on NORSAR recorded events on 7 May 1972. Most of this gain is due to replacing the cross-correlation procedures with beam-packing for signal line-up and omitting the depth calculations.

Statistical analysis shows that NORSAR reported 605, 505 and 470 events respectively for the months April, May and June 1972, which is 17 events per day in average. As the latter estimate is directly affected

by earthquake swarms, a better parameter is the median, which gives 16.8, 13.9 and 12.2 for the three months. The medians for May and June 1971 were 6.0 and 7.6 respectively, so the improvement is about a factor of two from the previous year. However, such a simple comparison is hardly valid due to varying noise conditions and seismicity rates, but on the other hand signifies more recent improvements in NORSAR performance.

The data from February - June 1972 has been studied extensively in order to find reliable estimates of detection thresholds for different regions. The 90% reporting threshold for all events within $30^{\circ}$ - $90^{\circ}$ range was 4.0 and the 50% threshold 3.6 $m_b$ magnitude units. The average NOAA/NORSAR bias is here 0.15 $\pm$ 0.31. Data regionalization shows that Central Asia is the best region with a 90% limit of 3.7 while Japan - Aleutians has 4.0 and Central-North America around 4.2 on the NORSAR magnitude scale.

As expected the new regional corrections implemented in January 1972 also reduced the average mislocation of events. Only data up to March is yet available from NOAA, and the comparisons show that for February - March 50% of the location differences are less than 150 km, while 90% are less than 500 km, for data in the $30^{\circ}$ - $90^{\circ}$ range. The corresponding numbers for December - January were 220 and 550 km. A regionalization study shows that Central Asia together with Japan - Aleutians are the best regions, while location errors in regions like Iran, Mid-Atlantic Ridge and in North America are much larger.

## V RESEARCH AND DEVELOPMENT

Research and development efforts in the reporting period have been focused on problems relevant to the NORSAR event detection capability. Moreover, a small attempt on multiarray signal processing has been undertaken.

The work on coherent and incoherent beamforming has continued in the reporting period and much attention has been given to the subarray beam amplitude distribution. For example, off-line simulation of the detection processor indicates that for the aftershock sequence of the Kamchatka earthquake of 15 Dec 1971, masking of half of the subarrays would not significantly decrease the array detection performance. The subarray amplitude distribution seems to be roughly log normal, although the individual subarray sensitivity varies considerably from one region to another. The problem of interest here is whether detection performance increases monotonically with the number of subarrays $N$ or in case of NORSAR have a maximum for $N$ less than 22.

Large earthquakes ($m_b \geq 7.0$) tend to saturate the Detection Processor for a period of 5-15 min. DP simulation using real data indicates that this problem may be greatly reduced by using high-frequency bandpass filters, say 1.6-3.6 Hz, for such events.

The event detection capability of a seismic array or a single station is essentially governed by the noise level. We are investigating the possibilities of predicting NORSAR's cumulative event detection capabilities in terms of $m_b$ magnitude units taking into account parameters like noise level, beamforming loss, EP threshold, etc. Preliminary results are in qualitative agreement with observational results.

The work on the possible gain in signal-to-noise ratio (SNR) using digital filters, considering many different Butterworth bandpass and prediction error (Wiener) filters, has progressed satisfactorily during the reporting period. Results based on real NORSAR noise and signal samples as well as a frequency domain synthesized analysis show that a proper bandpass filter would have a better performance than a prediction error filter. The filter performance depends mainly on two factors, namely, the dominant signal frequency and the filter slope towards the low-frequency noise. As both DP and EP have just one bandpass filter available for additional noise suppression, the gain in SNR is far from optimum in certain regions. This investigation would be completed in the near future.

So far most of our research has been tied to array or subarray beam data. More recently, work started on mapping of possible time, amplitude and signal similarity anomalies within the individual subarrays. The basic programs for extracting desired signal parameters have been completed.

A small experiment on multiarray processing has been initiated in the reporting period. The approach chosen is similar to that of incoherent beamforming, i.e., the signals are replaced by their envelopes. Using digitized WWSSN data of one earthquake and one explosion, the average envelope correlation coefficients are very high, having values around 0.7 - 0.9 units. Thus, in principle, incoherent beamforming using an arbitrary number of seismograph stations and arrays is possible. Precise travel time corrections are not required for this type of array processing due to the low frequency of the envelope signals.

## VI MISCELLANEOUS

During the reporting period a number of scientists, whose names are listed below, have visited NORSAR Data Processing Center, Kjeller, for special research purposes.

Dr. R.T. Lacoss, Lincoln Lab, M.I.T., Cambridge, Mass., U.S.A., in the period 4 April - 8 May 1972.

Dr. D.J. Doornbos, Utrecht University, Utrecht, The Netherlands, in the period 2 May - 30 June 1972.

Mr. W. Ellis, IBM, Federal Systems Division, Gaithersburg, Maryland, U.S.A., in the period 8 May - 26 May 1972.

Dr. I. Noponen, Seismological Laboratory, Helsinki, Finland, in the period 20 May - 30 June 1972.

Dr. B. Søderstrøm, Defense Research Institute, Stockholm, Sweden, in the period 29 May - 17 June 1972.

In the reporting period 85 data tapes were sent to SAAC.

K.A. Berteussen and H. Gjøystdal attended a seminar on Continental Drift, Sea Floor Spreading and Plate Tectonics in Newcastle-upon-Tyne, England, 10-14 April 1972.

H. Bungum, A. Dahle, H. Gjøystdal, E.S. Husebye, F. Ringdal and O. Steinert participated in the 3rd Nordic Seminar on Detection Seismology in Roskilde, Denmark, 8-10 May 1972. Altogether the NTNF/NORSAR group gave 5 talks.

H. Gjøystdal and E.S. Husebye attended a seminar on Geophysical Wave Theory at Voss, Norway, 12-15 June 1972.

F. Ringdal and O. Steinert participated in a course in Detection, Estimation and Modulation Theory in Brussels, Belgium, 26 June - 7 July 1972.

Reports completed in the 2nd quarter 1972

E.S. Husebye (prepared): Progress Report NORSAR Phase 3, 1st quarter 1972, NORSAR Report No. 25, 1972.

E.S. Husebye: Seismic arrays and seismology, Acta Univ. Upsaliensis, No. 223, 1972.

H. Gjøystdal, E.S. Husebye and D. Rieber-Mohn: One array and two array location capabilities, NORSAR Technical Report No. 29, 1972.