Royal Norwegian Council for Scientific and Industrial Research

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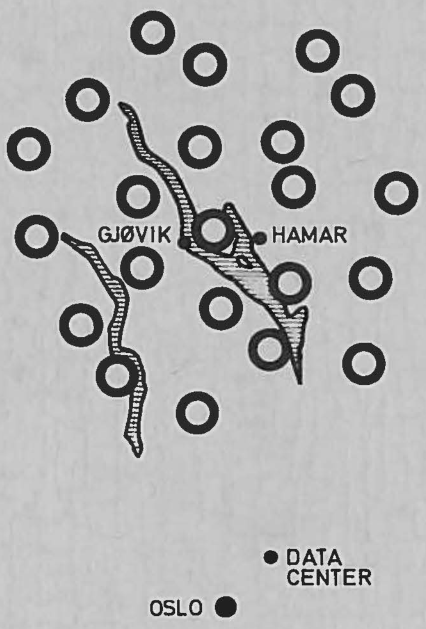
PROGRESS REPORT
NORSAR PHASE 3

1st Quarter 1973

Prepared by

E.S. Husebye
(Chief Seismologist)



NORWEGIAN SEISMIC ARRAY

NORSAR

P. O. Box 51. 2007 Kjeller – Norway

NTNF/NORSAR
Post Box 51
N-2007 Kjeller
Norway

NORSAR Report No. 59

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15 May 1973

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, through contract F-19628-70-C-0283 with the Royal Norwegian Council for Scientific and Industrial Research.

This report has been reviewed and is approved.

Richard A Jedlicka, Major USAF
Technical Project Officer
Oslo Field Office
ESD Detachment 9 (Europe)

ARPA Order No. 800 Program Code No. IF10

Name of Contractor	:	Royal Norwegian Council for Scientific and Industrial Research
Date of Contract	:	15 May 1970
Amount of Contract	:	$2,051,886
Contract No.	:	F19628-70-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

ABBREVIATIONS

BE card	-	Lightning protection card of data channel
COMSAT	-	
CTV	-	Central Terminal Vault in a subarray
DCAA	-	Defence Contract Audit Agency
DP	-	Detection Processor
EOAR	-	European Office of Aerospace Research
EP	-	Event Processor
ESD9	-	Electronic Systems Division, Detachment 9
LP	-	Long Period
LTA	-	Long Term Average
NAS	-	NORSAR Analog Station
NDPC	-	NORSAR Data Processing Center, Kjeller
NMC	-	NORSAR Maintenance Center, Stange
NOAA	-	National Oceanic and Atmospheric Administration
RMS	-	Root-mean-square
SDAC	-	Seismic Data Analysis Center, Alexandria, Va.
SLEM	-	Short and Long Period Electronic Module
SNR	-	Signal-to-noise Ratio
SP	-	Short Period
TAL	-	Trans-Atlantic Link
TIP	-	Terminal Interface Processor

SUMMARY

The report covers the period 1 January - 31 March 1973 which is characterized by improving, estimating and simulating the array detection capability. The operational performance of the field equipment has been satisfactory also in this reporting period, and some relaxation in the computerized array monitoring schedules has been instituted. The operation of the Detection Processor has been very satisfactory. The task of connecting NORSAR to the so-called ARPANET is in progress. The event reporting capability was significantly better in this reporting period than in the corresponding period in 1972. The potential of using amplitude weights in the array beamforming has been investigated and a gain in SNR amounting to 4-6 dB for 8 randomly selected very weak events in Central Asia was achieved. Event magnitudes as reported by NORSAR are similar to those of NOAA for small events ($m_b \sim 4.0$) but below NOAA for relatively large events.

1. ADMINISTRATION AND ECONOMY

Representatives for Air Force Office of Scientific Research (AFOSR), Lt Col Wallace (EOAR), Lt Col Stevens (EOAR), Capt Rourke and Lt Col Heath (ESD9), visited NORSAR 7-8 February. The purpose of the visit was familiarization with the array and its operation, research projects and future plans.

Mr. Figueiredo from Defence Contract Audit Agency (DCAA) visited NORSAR 20-23 March and performed an audit on the NTNF proposal for operation of NORSAR 1 July 1973-30 June 1975.

Mr. Klisch from COMSAT visited NORSAR 29 March for a discussion on satellite communication links which are an integral part of the data exchange with the Seismic Data Analysis Center (SDAC) in Washington.

Expenditures in the period 1 January - 31 March 1973:

1.	Operation & Maintenance		
	1.1 Data Processing Center	$88,196	
	1.2 Field Installations	45,315	
	1.3 Data Communications	20,377	$153,888
2.	Research & Development		13,725
3.	Administration & Support		15,762
	Total		$183,375

2. ARRAY MONITORING AND FIELD MAINTENANCE

The performance of the array's field instrumentation has been stable and satisfactory. This has resulted in a small activity in the field maintenance work and a further relaxation in the schedule of remote array monitoring at the data center at Kjeller (NDPC). The new maintenance center (NMC) at Stange was taken in use in January, while the installation of test and maintenance equipment has continued throughout this period. The output from an additional SP seismometer installed at 05C is being transmitted to NDPC in analog form and registered on a Helicorder recorder. The analog station, code name NAS, was tested out during December 1972 and became operative in January 1973. Station magnification is presently 35K . The response characteristics are shown in Fig. 1.

NDPC Activity

Based on our experience with error rates disclosed by the array monitoring (AM) programs, the CHANEVSP/LP program runs have been changed from a monthly to a

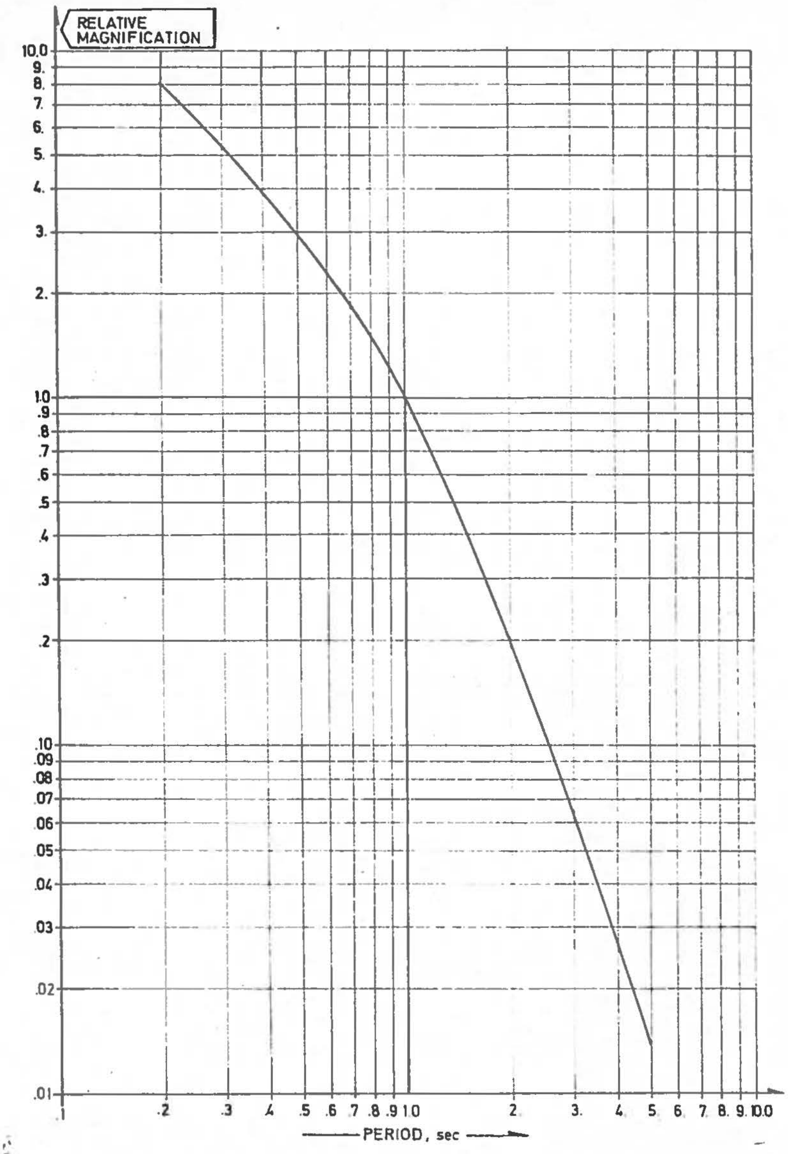

Fig. 1 Magnification of NORSAR SP Analog Station relative to Magnification at 1.0 sec period.

6th-weekly monitoring basis. Table 1 shows the present AM schedule as of 31 March 73. The off-line computer time requirement per month in average is now 34 hours.

The off-line analysis programs have been modified and improved to facilitate the access to previous monitoring results and also including options for trend studies of data channel performance. Modifications of the

AM Program	Rate
LPCAL (LP Sensor Calibration)	Biweekly
SLEMTEST (SLEM Check)	Biweekly
MISNO (A/D Conversion Check)	Monthly
CHANEV (Frequency Band Analysis)	6th Weekly
SACP (Single Frequency Analysis)	
SP	Bimonthly
LP	6th-monthly
Visual Check:	
Sensor Time Series	Daily
Sensor Gain and Phase	Biweekly

TABLE 1

Array Monitoring Schedules for the Individual Subarrays.

CHANEV programs and updating of internal program parameters have been accomplished. A status report of all data channels is generated daily and is available to users of NORSAR data.

NDPC and NMC Activities

A number of investigations for improving the field equipment have been initiated in the reporting period. Among these should be mentioned:

- Option for remotely introducing calibration signals to the NAS seismometer
- Suppression of noise in SLEM discrete input signals
- Modification of CTV emergency lights
- Improvement of BE protection cards

- Modification of CTV water monitor
- Investigation of trends in SP LTA DC offset towards negative values.

The preparations for permanent on-line connection between NMC and NDPC have been accomplished.

3. COMPUTER CENTER OPERATION - DATA PROCESSING

3.1 Programming Efforts

In order to make the data on the event tapes more easily accessible, a program was designed to scan the event tapes and print all the events found in the same sequence they were stored on the tape. Optionally, restrictions may be put on location, magnitude, period and detection partition (coherent or incoherent) of the events to be listed.

A program was made which reads the low rate tape and prints out the entries in the SDAC seismic bulletin which also are recorded on this tape. A difficult problem is the random occurrence of missing data blocks, which lately has happened quite frequently. If both data blocks giving an entry are missing, a set of asterisks is substituted in its place.

To facilitate the manual analysis of the Event Processor output, a program has been developed for calculating geographical event location, travel time and magnitude correction factor for an event, when input is one of the following:

- Distance, azimuth, depth and phase
- U-space coordinates, depth and phase
- Velocity, azimuth, depth and phase.

The input/output unit used is the 2260 display station. This arrangement gives the analyst an option to use different event solutions in one run.

A program has been developed for extracting relevant parameters for testing two short period discrimination criteria. The first step is scanning of one or more event tapes, and then to compute the average subarray beam power spectrum, the third moment of frequency on this spectrum, and the complexity of the array beam trace for the events specified.

Detection Processing

The Detection Processor (DP) was recording data on-line for approximately 99.3 % of real time in January, 98.7% in February and 99.5% in March. Total down time was thus 19 hours in this period.

In the reporting period there were no serious problems in operating the on-line system.

The Detection Processor A-filter (selected surveillance) was changed from 1.4-3.4 Hz back to 1.2-3.2 Hz effective 2 January 1973 at 0811 GMT.

The bad quality of the on-line transmission from SDAC to NDPC (TAL) was prevailing throughout this period.

Event Processing

The number of events reported in Jan-Mar 1973 are listed in Table 2. The seismic background noise has, as expected, been somewhat troublesome these winter months, although the array's event reporting performance was significantly better than the same period last year.

Month	Teleseismic	Core	Total
Jan 73	401	86	487
Feb 73	412	90	502
Mar 73	489	92	581

TABLE 2

NORSAR Reported Events in the 1st Quarter 1973

The editing of a special NORSAR DP bulletin for internal use has continued and Table 3 shows the results when compared with the final EP bulletin. The false alarms are mainly later phases reported as separate events, and local explosions and earthquakes.

Month	False Alarms	Misses
Jan 73	15.6%	21.6%
Feb 73	11.8%	22.1%
Mar 73	12.4%	21.7%

TABLE 3

NORSAR DP/EP Bulletin Comparison

The acceptance threshold is set so high that few false alarms are due to noise detections, and this is also the reason for the undetected events.

A special comparison of the event reporting performance of the Hagfors array vis a vis NORSAR was carried out for three weeks between 02 Mar and 22 Mar 1973. Our DP bulletin was sent daily by telex to Sweden, as Hagfors wanted to evaluate a new reporting procedure. Some preliminary results are presented in Table 4, which shows that a large percentage of the events detected are reported by both arrays. It is difficult to undertake a more detailed comparison between the above bulletins as the records have been analyzed by different persons and thus the noise false alarm probability could be different. Around 25% of the events now reported by Hagfors are localized.

Daily Average 03/02-03/22	NORSAR	Hagfors	NORSAR Only	Hagfors Only	NORSAR & Hagfors
Number of Events	18.1	13.7	7.8	3.4	10.4

TABLE 4

NORSAR/Hagfors Bulletin Comparison

NORSAR Data Transmission via the ARPANET

In the fall of 1972 ARPA proposed to connect the NORSAR array to the so-called ARPA Network, i.e., the ARPA sponsored interlinking of around 40 intermediate and largely dissimilar computers in the United States. Current plans include installation of a Terminal Interface Processor (TIP) with associated equipment at NORSAR DPC. The present 2.4 Kb satellite link with the U.S. will be upgraded to 9.6 Kb, and corresponding new 9.6 Kb modems installed. Initially, the ARPANET link will be restricted to seismic data exchange between NORSAR and SDAC to the same extent as before, with the potential of future expansion of network use. Also, the NORSAR TIP will act as entry point to the ARPANET for the Institute for Computer Science, London University, via a new 9.6 Kb link between London and Kjeller. Installation of new equipment at NORSAR DPC is scheduled for mid-June 1973.

4. RESEARCH AND DEVELOPMENT

Research and development efforts have been focused on problems relevant to the NORSAR event detection capability and system evaluation as in the previous period.

Weighted Array Beamforming

The observed P-signal amplitude distribution across the NORSAR array may be approximated by a lognormal probability density distribution. Moreover, the background noise varies from one subarray to another when measured over short time intervals. Obviously, weighting functions based on observed amplitude and/or noise fluctuations would improve the SNR gain during beamforming processing. The above problem has been investigated, and the following signal processing schemes have been considered:

1) Standard or equal subarray weights: (SNR)

$$Y_j = S + N_j \qquad \sigma^2(N_j) = \text{const.}$$

$$\hat{S} = \sum_{i=1}^{Nsub} Y_j \qquad \text{Correct line-up assumed}$$

where Y_j is the P-signal recorded at the j-th subarray, S is the signal, N is the background noise, σ^2 denotes the variance, $\hat{S}$ is the estimate of the 'true' signal or array beam, and Nsub is the number of subarrays used in the beamforming process. Note, in this model the P-signals are taken to be identical, noise level fluctuations ignored and correct line-up assumed.

The operational principles of NORSAR and LASA are based on the above signal model which is clearly not optimal.

2) Root-mean-square (RMS) weight function:

$$Y_j = S + N_j \qquad \sigma^2(N_j) \neq \sigma^2(N_i)$$

$$\hat{S} = \sum_{i=1}^{Nsub} Y_j/\sigma_{N_j} \qquad \text{Correct line-up assumed}$$

This model is similar to the previous except for introducing weights inversely proportional to the subarray noise level.

3) Amplitude pr weight function (AMP):

$$Y_j = \gamma_j \cdot S + N_j \qquad \sigma^2(N_j) = \text{const.}$$

$$\hat{S} = \sum_{i=1}^{Nsub} \hat{\gamma}_j Y_j$$

In this model, the subarray signals are not assumed to be identical across the array. Note that the weight function γ may take negative values, implying that errors in signal line-up may be partly corrected during the beamforming process.

4) Root-mean-square and amplitude weight function (R&A):

$$Y_j = \gamma_j S_j + N_j \qquad \sigma^2(N_j) \neq \sigma^2(N_i)$$

$$\hat{S} = \sum_{i=1}^{Nsub} \hat{\gamma}_j Y_j/\sigma(N_j)$$

In this model, both signal amplitude and noise level are taken as variables.

The calculation of the RMS-weights is straightforward, while the optimal estimation of the amplitude weight function is described in a paper by Christoffersson and Jansson (1969). Actually, the above investigation was initiated during a recent research visit by Dr. Christoffersson to NORSAR DPC in the reporting period. Significant gain in SNR on the array beam level has been obtained by introducing RMS, amplitude (AMP) and RMS-amplitude (R&A) weights in the beamforming processing. Some of the results obtained are displayed in Tables 5 and 6. The obtainable gain in SNR varies from one case to another but is most impressive for small events where signal line-up may be in error.

The computer time required for calculating amplitude weights is between one and two minutes, so Event Processor implementation of amplitude weighting is under consideration. The same applies to the Detection Processor as the signal

No.	Region	SNR	RMS	AMP	R & A
1	W. Russia	2.46	0.15	6.02	6.60
2	W. Russia	3.00	0.16	4.84	5.14
3	Uzbek SSR	2.73	0.09	2.04	2.74
4	C. Kazakh	3.21	0.39	0.41	2.52
5	Sinkiang	3.04	0.12	5.20	5.11
6	Czechoslovakia	1.89	0.78	7.65	7.20
7	Ural Mountains	3.21	0.16	1.85	2.21
8	W: Kazakh	1.51	-0.09	3.48	5.91

TABLE 5

Relative processing gains for difficult events in Eastern Europe and Central Asia. The SNR column gives the signal-to-noise ratio during on-line detection processing. The columns RMS, AMP and R&A give relative gains in dB by using different weighting functions.

No.	Region	Bandpass Filters Used											
		1.0-3.6 Hz				1.2-3.2 Hz				1.6-3.6 Hz			
		SNR	RMS	AMP	R & A	SNR	RMS	AMP	R & A	SNR	RMS	AMP	R & A
1	Caribbean	3.35	0.13	0.42	1.16	3.92	0.09	-0.23	0.46	3.24	0.07	-0.64	1.38
2	Kamchatka	2.88	-0.14	1.09	1.65	3.37	0.15	1.04	1.79	2.60	0.19	2.63	3.27
3	Sudan	6.52	-1.02	4.32	4.56	6.83	-0.74	4.81	5.17	7.03	0.11	5.46	5.03
4	Egypt	5.83	0.46	6.08	6.37	5.71	0.56	4.96	8.07	4.80	1.31	8.85	10.17
5	Greenland S.	75.95	0.29	1.94	4.04	55.54	1.21	1.02	5.15	27.80	2.03	-2.38	7.40
6	Ryukyu	627.19	-0.13	1.14	1.15	605.29	-1.04	1.62	1.81	428.86	-0.43	1.44	1.42
7	Kamchatka	50.31	0.32	0.45	0.90	50.21	0.38	-0.44	0.27	43.35	0.32	0.13	0.46
8	Ryukyu	9.42	0.83	1.42	2.13	10.42	1.10	2.62	3.40	8.73	0.73	0.58	1.32
9	Norfolk	4.31	-0.09	1.98	2.08	4.32	0.17	2.70	2.79	3.10	-0.26	4.52	4.69
10	Kermandec	3.63	-0.30	0.93	1.29	4.05	-0.44	1.07	1.22	4.43	-0.41	1.01	1.13

TABLE 6

Relative processing gains for randomly selected but relatively strong events. (For table entries' explanation, see text for Table 5.) Except for more local earthquakes, i.e., the Greenland Sea and Egypt-Sudan (same event by different locations), the weighting gains are between 1 and 2 dB. In general, the amplitude weighting score increases with decreasing SNR, and is not sensitive to the bandpass filter used.

EVENT NO.	RMS	AMP	R & A	MASTER
1	0.62	1.28	1.10	0.98
2	0.76	2.63	2.84	0.65
3	0.23	3.03	2.98	3.07
4	0.25	3.44	3.24	2.29
5	0.30	3.23	3.70	2.86
6	0.25	3.23	4.13	0.80
7	0.01	2.29	2.36	2.34
8	0.16	1.88	1.98	2.22

TABLE 7

Relative processing gains in dB for 8 different earthquakes in Japan. The MASTER column gives the score based on standardized amplitude weights. The latter were taken as the average of amplitude weights for 10 good (the so-called master) events in the Japan region.

amplitude pattern is stationary for a certain region, i.e., it is repeated from one event to another. Relevant results for this case using events in Japan are shown in Table 7.

Bias Analysis of NORSAR m_b Magnitude Estimates

In general, NORSAR reported event magnitudes are somewhat smaller than those of NOAA. This effect has tentatively been explained in terms of signal losses during the beamforming processing. The problem has been investigated in detail, and the main results obtained are as follows:

The NORSAR event magnitude estimation depends on two special effects, namely, signal loss during beamforming and the skewness of the subarray amplitude distribution. The negative bias in m_b due to signal loss is in average compenstated for by a positive amplitude skewness bias. A detailed comparison between NORSAR and NOAA reported event magnitudes in general gave the following results. For small events, $m_b \leq 4.0$ NORSAR and NOAA in average give the same event magnitudes. For intermediate events, NORSAR reports too small m_b-values relative to NOAA, but this magnitude difference decreases for $m_b > 5.5$. Analysis of event magnitudes reported by conventional stations gave essentially the same results, i.e., magnitude station corrections are a function of event magnitude. In general, these corrections are assumed to be constant for a specific region.

False Alarm Rate

The NORSAR false alarm rate for a fixed threshold does vary with changes in the characteristics in the background noise as demonstrated and explained by Lacoss (1972). We are continuing this work, aiming at updating the detection threshold for the Event Processor each 4-6 hours. Preliminary results give that changes in the false alarm rate are adequately explained by the noise stability parameter, i.e., the mean square of the noise divided by its variance. However, the observed values, obtained from off-line Detection Processor data analysis, are somewhat larger than those predicted from the model of Lacoss (1972). We should also like to mention that the noise level is relatively small during nights, but the event detectability is likely to be constant on a diurnal basis as noise stability is better during daytime. However, due to lack of flexibility in threshold setting around 5% more events are reported during the night relative to during the day.

5. MISCELLANEOUS

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

Dr. I. Noponen, Seismological Institute, Helsinki, Finland

Dr. A. Christoffersson, Statisitical Institute, Uppsala University, Uppsala, Sweden

Dr. E. Hjortenberg, Geodetic Institute, Copenhagen, Denmark

During the reporting period, Cand. real K. A. Berteussen, NORSAR DPC, visited the Seismic Discrimination Group, Massachusetts Institute of Technology.

In the reporting period 90 data tapes were sent to SAAC. Three data tapes were sent to E. Rygg, Seismological Observatory, Bergen, and two tapes were sent to Dr. E. Hjortenberg, Geodetic Institute, Copenhagen.

Reports completed in the period

No. 53	Husebye, E.S., Progress Report 4th Quarter 1972
No. 54	System Operations Report, 1 Jan - 30 Jun 72
No. 55	Hokland, B., Operating Instructions for EP/ Job Step 4 Editing
No. 56	System Operations Report, 1 Jul - 31 Dec 72.

REFERENCES

Christoffersson, A., and B. Jansson: Maximum-likelihood Estimation of an Unknown Signal in Multiple Gaussian Noise with Known Covariance Matrix, Sixth UMC Symposium on Geophysical Theory and Computers, Copenhagen, August 1969.

Lacoss, R.T.: Seismic Discrimination, Semi-annual Technical Summary, M.I.T., Lincoln Laboratory, 30 June 1972.