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PROGRESS REPORT NORSAR PHASE 3

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Royal Norwegian Council for Scientific and Industrial Research

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report covers operation and research activities at the Norwegian Seismic Array (NORSAR) in the period 1 July - 30 September 1974. The performance of the field instrumentation and computer installations has been stable with a normal amount of corrective maintenance. The ARPANET terminal is used routinely for data exchange. In the Event Processor a new program package which will calculate optimal beamforming weights for some selected unclear detections is in progress. In the Detection Processor a floating threshold procedure is in development. In connection with this a study of the seasonal and diurnal

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) noise variance fluctuations and their effect on earthquake detectability has been finished. It has further been shown that the short-periodic seismic noise at NORSAR can be described by autoregressive models. A study of the mechanism of North Atlantic earthquakes has been undertaken. Finally a new method for inverting travel time anomalies has been tried on the NORSAR, LASA and California array.

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1. ADMINISTRATION AND ECONOMY

All subcontracts for the period 1 July 1974 - 30 June 1975 have been signed by both parties and are approved by the Administrative Contracting Officer.

A Post Award Conference concerning the new contract was held 20 August 1974. The meeting was initiated and led by Mr. Wasserman, Administrative Contracting Officer (ACO).

Mr. D. Madrigal, Property Administrator from Det 16 Air Force Contract Maintenance Center (AFCMC) performed a property survey in the period 21 - 29 August 1974.

The field maintenance staff was reduced with one technician as of 1 July 1974. The total number of field technicians is now four.

<u>Economy</u>

1.	Operations and Maintenance			
	1.1	Data Processing Center	$ 124,077	
	1.2	Field Installations	$ 23,220	
	1.3	Data Communications	$ 36,798	$ 184,095
2.	Research and Development			$ 4,559
3.	Administration and Support			$ 21,240
			Total	$ 209,894

2. ARRAY MONITORING AND FIELD MAINTENANCE

The performance of the array's field instrumentation has been stable throughout this period. The amount of general corrective maintenance has been normal for the season with the main work load on repair of cable breakages and lightning protection cards. The preventive maintenance program including replacement of seismometer amplifiers and Well Head Vaults (WHV) construction maintenance has been delayed this fall. Work is remaining on 02C03-06; 10C01-03; 12C01-03,05,06 and 14C and will be completed next spring. The NORSAR Analog SP station magnification was reduced from 55.0 K to 37.5 K as of 9 September.

2.1 NORSAR Data Processing Center (NDPC) and NORSAR Maintenance Center (NMC) Activity

A report on accomplished modifications, recommended in previous reports, on NORSAR SP and LP instrumentation is under preparation.

The NORSAR Analog SP station will be moved to NMC during October this fall. The recorder drum and amplifier will then be located at NMC and connected to 04B05 seismometer through a separate RA-5 seismometer amplifier. Solutions to the technical layout problems have been worked out.

The part of the Nordic Kirnos Project involving operation of a Kirnos broad band seismometer at NORSAR is now completed. Recording was terminated 20 September and the instrumentation was dismantled and packed shortly after. Reshipment to the University of Helsinki will take place in October. A report on the operation of this station will be issued.

2.2 Field Maintenance

A few of the main time-consuming work tasks should be mentioned. Thirty-eight work days have been spent on cable repair, mainly on cable breakage at 10C04,05, caused by lightning. Table 1 shows the cable breakages in the period. Twenty-six lightning protection cards have been replaced or repaired. Eleven Line Termination Attenuators have been replaced due to pre-sampling filter faults or faulty relay (K2). Seven LP seismometer remote centering devices have been replaced, which is more than normal.

Sub-array	WHV Cable	Main Data Cable	Breakage (Out of Operation)	
			From Date	To Date
01A	02		12 July	16 July
05B	01,05		25 September	27 September
01C		x	20 June	5 July
03C 04C 05C		x	19 June	5 July
07C	03		25 June	3 July
10C		x	2 July	14 August
	04,05		20 August	out period
14C		x	24 June	3 July

TABLE 1

Cable breakages at NORSAR in the third quarter of 1974.

3. COMPUTER CENTER OPERATION AND DATA PROCESSING

3.1 Data Center Operation

No serious machine failures occurred in the period, as indicated by the Detection Processor (DP) figures below. DP non-recording time is accounted for by one Special Processing System (SPS) stop of 5.5 hours and a few power failures caused by thunderstorms in the area.

Total DP non-recording time in quarter:	19.5 hrs (0.9%)
SPS down time	5.5 hrs (0.25%)
A computer down time	59 hrs (2.7%)
B computer down time	15 hrs (0.6%)
Average communication line down time	71 hrs (3.2%)

One subarray (10C) communication line was down for several weeks due to a burnt-out ground cable (lightning stroke). Excluding this, the average communication line outage was 41 hrs (1.8%).

The Trans-Atlantic and U.K. links performed satisfactorily, with only short and occasional breaks.

The ARPANET Terminal Interface Processor (TIP) failed and was routinely restarted 7 times in the period. Approx. 2130 jobs (excluding routine jobs) were run in the job shop.

3.2 Programming Efforts

The following programs were developed inthis period:

- a program that, based on a card-punched input of the DP down time history in the last half year computes various parameters and plots a diagram giving down time each day

- a FORTRAN compatible tape write subroutine that writes binary records of arbitrary length to a tape, as well as tape marks

- a FORTRAN compatible tape handling subroutine for forward/backward spacing of files on a multiple tape.

3.3 Detection and Event Processing

During this period a floating threshold procedure has been under development in the Detection Processor. This involves continuous calculation of noise stability, and final implementation is expected later this fall.

Because of requirements connected to the Network Control Programs (NCP) for the ARPANET connection the low priority message task in DP has been implemented on an overlay basis.

In the Event Processor (EP) a new package is under development which will calculate optimal beamforming weights for some selected uncertain detections. The package will also include three different statistical tests for signal-noise classification, and this may prove very useful to the analyst.

3.4 The NORSAR Terminal Interface Message Processor (TIP) Connection

Our ARPANET terminal attachment is used routinely for transmission of the NORSAR bulletin to the message file of the U.S. Geological Survey (USGS) at OFFICE-1 (Stanford University) and for information exchange with Seismic Data Analysis Center (SDAC), Lincoln Laboratory's Seismic Discrimination Group and other institutions.

To insure safe delivery of our bulletin to the USGS message file, we now deliver the bulletin directly to USGS file, instead of using the SNDMSG facility from Stanford Research Institute, SRI-ARC. This is done in agreement with USGS, who has furnished us with their directory name and password at OFFICE-1.

At the present time nothing is known about how the future exchange of seismic data between the NORSAR 360/40A and the SDAC Communications and Control Processor will take place .

4. RESEARCH AND DEVELOPMENT

4.1 Some Autoregressive Models for Short-Periodic Seismic Noise

It is shown that short-periodic seismic noise at the NORSAR seismic array can be described by a parametric model having the form

$$X(t)-a_1(t)X(t-1)-\ldots-a_p(t)X(t-p) = Z(t)$$

where X(t) is used to denote the noise process. This is a nonstationary generalization of the standard autoregressive models allowing time-varying autoregressive coefficients and a nonstationary white noise residual process Z(t). The coefficients $a_1(t)$, $a_2(t),\ldots,a_p(t)$ and the residual variance $\sigma_z^2(t)$ are estimated using data from the NORSAR seismic array. It is found that the short-periodic noise at NORSAR is quite satisfactorily described by a 3rd (p=3) order model. Also, it is found that the nonstationary character of the noise is due primarily to time-variations of the residual variance and the lower order autoregressive coefficients. This work has been undertaken by D. Tjøstheim.

4.2 Seasonal and Diurnal Noise Variance Fluctuations and Earthquake Detectability

The problem of declaring a signal detection represents a hypothesis test based on the test statistic η, η being the ratio between the linear array beam power measured in a short (STA) and a long time window (LTA). A detection is declared whenever η is equal to or exceeds a preset detection threshold (TH), i.e., hypothesis H_1 is chosen. Otherwise, decide that H_1 is false, i.e., hypothesis H_0 is chosen. This binary decision model has two conditions: the false alarm or choosing H_1 when H_0 is true, and the missed detection or choosing H_0 when H_1 is true.

The design of the NORSAR detector was primarily governed by its computational simplicity and not derived from any optimum criteria, especially because the noise likelihood function was not exactly known. However, we know that the noise exhibits both diurnal and seasonal fluctuations. This means that the test statistic η is unstable, which implies a variable false alarm probability for a given detection threshold. As of today, a fixed threshold value is used in the array's detector causing a larger number of false alarms during night time as compared to day time operation. As the detector is insensitive to noise level fluctuations (Bungum and Ringdal, 1974), this phenomenon has to be attributed to changes in noise variance. A study to investigate this effect has been accomplished.

The most successful false alarm indicator considered, called the noise stability, is defined as

$$S = \frac{\overline{STA}^2}{\sigma^2(STA)} \quad (1)$$

where the bar indicates averaging and σ^2 is the variance of STA. S is a generalized measure of the spread in the η observations.

A mathematical relation between TH, S and false alarm rate has been established, i.e.,

$$TH(dB) = 12.08-(0.89\pm0.10) \log FA -(0.18\pm0.02)\cdot S \quad (2)$$

where FA is number of false alarms per hour. The false alarm rate is defined as the sum of all detections reported to have an STA/LTA ratio larger than given detection thresholds. "True" detections were defined as STA/LTA larger than 10.5 dB and henceforth removed from the sample population. Noteworthy, the noise stability-false alarm relationship was found to be

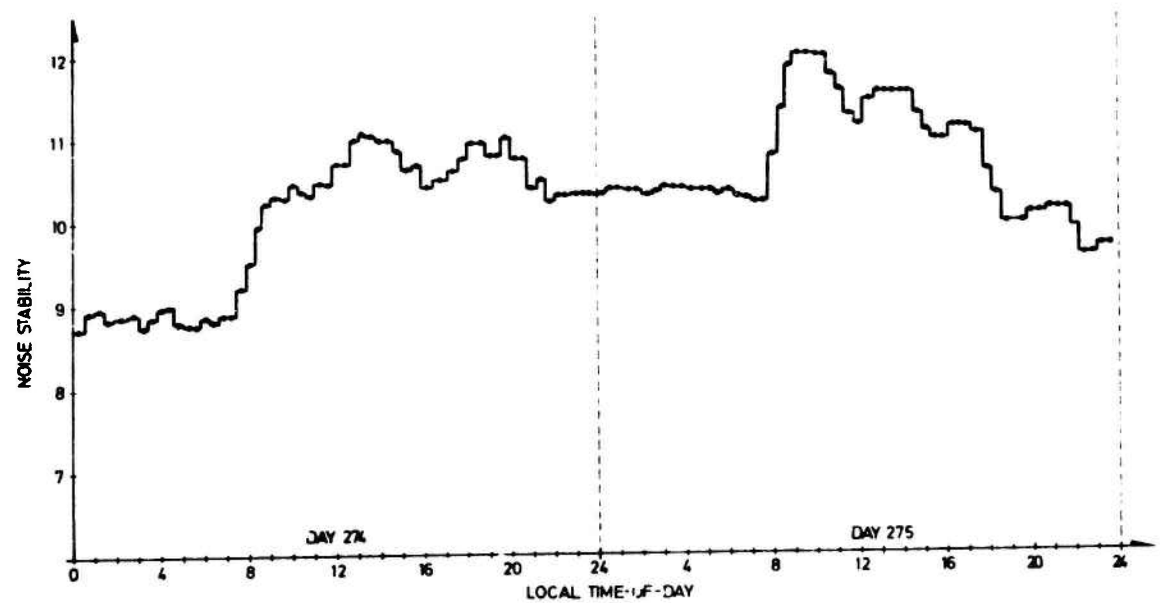

Fig. 1 Noise stability as function of local time-of-day. The values have been smoothed with emphasis on large stability values, i.e., shown is average of three largest out of six successive.

independent of whether the noise field varies naturally or artificially by using bandpass filters. Eq. (2) makes it possible to fix the false alarm rate and let the threshold vary as function of noise stability. It can be shown that implementation of a floating threshold will imply an average gain in the number of reported events of a few per cent relative to a fixed threshold procedure. Other advantages are avoidance of system saturation during extremely noisy time periods, and a more economical use of the computer capacity. The floating threshold procedure is being tested in parallel with the present (fixed) on-line detection threshold. Fig. 1 shows the variation of the noise stability, calculated approx. every 24 minutes, as function of time-of-day for days 274 and 275, 1974. The scatter in the stability values is quite large and a reduction procedure with emphasis on higher values has been exercised. The trend in these results on a diurnal basis is in agreement with Bungum and Ringdal (1974). This study will continue. For further details on this topic we refer to a forthcoming paper authored by Steinert et al (1974).

This work has been undertaken by O. Steinert, E.S. Husebye and H. Gjøystdal.

4.3 Surface Wave Studies

Most of the research efforts at NORSAR have been directed towards the array's event detection and location capabilities. However, for reliable earthquake-explosion discrimination surface wave information is badly needed. In order to gain the necessary insight in the sophisticated processing techniques currently used in analysis of surface waves, we have as a first step started an investigation of the mechanisms of N. Atlantic earthquakes. Preference was given to this area because the epicentral distance is small (Aki and Husebye, 1974), thus minimizing complex multipathing effects and also because the seismicity of this region is well known (Husebye et al, in press).

Another approach to surface wave analysis presently under investigation is to introduce parametric models for signal description. If such techniques prove successful, we may be able to efficiently map surface wave spectral peculiarities as a function of seismic region, and also use an integrated surface wave power estimate in magnitude measurements.

4.4 Travel Time Inversion

P-wave travel time and amplitude anomalies observed for large aperture arrays like NORSAR and LASA or similar types of seismograph networks cannot satisfactorily be explained in terms of regional crust and upper mantle models, say, based on refraction and wide-angle reflection seismic profiling surveys. Besides, structural inhomogeneities in the mantle or in the source region are in general discarded here, as the time and amplitude anomalies have a wave length between 15-40 km.
A new approach to the above problem which is of considerable importance to seismology, is to introduce inversion techniques. The equation used for modelling travel time observations is (see also Fig. 2)

$$T = G\,m + \varepsilon \qquad (1)$$

where T is observed time anomalies, the G-matrix contains travel path information, m is the velocity perturbation and ε is the residue. The least squares solution is:

$$\hat{m} = m + (G'G)^{-1} \cdot G'\varepsilon \qquad (2)$$

In general, the G-matrix is singular, i.e., even for well-posed data the rank of G is reduced by a factor of 1 for each layer in the model because it is natural to require that the average of the velocity anomalies is equal to zero for each layer. Therefore, a constant ε^2=250 was added to the diagonal terms prior to inversion of the G-matrix. This

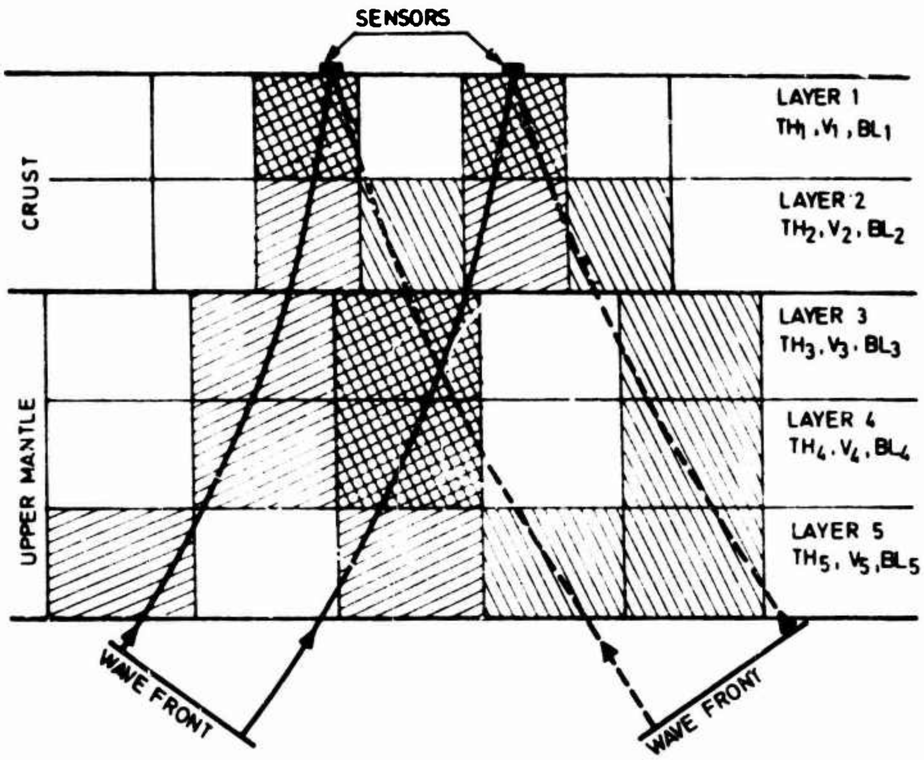

Fig. 2 Schematic view of cross-section of crust-upper mantle model used for time anomaly inversion. Model specification is given by number of layers, layer thickness, P-velocity in the layer, and size of the blocks being either rectangles or squares. The block size may vary from one layer to another, and being largest for the bottom layers. The blocks sampled for two events recorded at two sensors are shaded. The problem is to estimate the P-velocity perturbations for the individual blocks.

operation corresponds to a smoothing of the solution. Alternatively, we may first compute the exact solution and then smooth using a predefined filter. It should be noted that the final estimate of the velocity anomalies is not very sensitive to the layer thickness and velocity, while the block size parameter is relatively more important. Also, it is sufficient to use max. 5 layers as adding an extra layer does not result in a significant reduction of the residual variance of the travel time anomalies.

A comprehensive discussion of the above method, and also the results obtained in analysis of NORSAR, LASA and California array data are given in a forthcoming paper by Aki, Christoffersson and Husebye.

5. MISCELLANEOUS

5.1 Visiting Scientists

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

Dr. I. Noponen, University of Helsinki, Finland, 4 July - 27 July.

Dr. G. Calcagnile, University of Bari, Italy, arrived 22 July for a one-year stay.

Dr. S. Pirhonen, University of Helsinki, Finland, 24 July- 9 August.

Lt. Col. N. Orsini and Dr Thurber (U.S. Geological Survey), 29 July - 30 July.

Dr. A. Christoffersson, University of Uppsala, Sweden, 29 July - 10 August.

Dr. G. Ranalli, Carleton University, Canada, 9 August - 13 August.

Mr. Ami Ziv, Scientific Counsellor, Israeli Embassy in London, 28 August.

Dr. P.K.H. Maguire, University of Leicester, United Kingdom, with a group of geology students, 13 September.

Dr. R.J. Brown, University of Manitoba, Canada, arrived 15 September for a one-year stay.

5.2 Meetings

N. Marås, H. Bungum, A. Dahle, J. Fyen, D. King, G. Purcaru and G. Calcagnile attended the European Seismological Commission meeting in Trieste, Italy, 15-26 September. The following papers were presented:

H. Bungum: The effect of multipath propagation on surface wave dispersion analysis.

A. Dahle: P-wave parameter fluctuations across NORSAR related to the random medium concept.

J. Fyen: Signal-noise classification.

D. King: Precursors to PP and the P coda.

G. Purcaru: A new magnitude-intensity relation of Vrancea-Carpathian intermediate earthquakes.

- Quasicycles, time-magnitude "gaps" and possible criteria for the prediction of earthquakes in time and magnitude.

- Vrancea-Carpathian earthquakes and plate tectonics in the region of Romania and its vicinity.

G. Purcaru and M. Katsumata: Depth-magnitude distribution of large earthquakes in the region of Japan and some related aspects.

G. Purcaru and K. Aki: Seismic moments of the largest earthquakes and their implications on the problem of maximum magnitude.

5.3 Reports Completed

The following reports were completed in the third quarter of 1974:

Berteussen, K.A.: Progress Report, 2nd Quarter 1974.

Bungum, H. (Ed.): Semiannual Technical Summary, 1 Jan - 30 Jun 1974, Scientific Report No. 6-73/74.

Aki, K., and E.S. Husebye: Preliminary Report on and Proposal for Future Focal Mechanism Study of N. Atlantic Earthquakes, Scientific Report 2-74/75.

Marås, N.: NORSAR Reports Specifications and Standards, Internal Report No. 1-74/75.

Marås, N.: NORSAR Research and Operations Plan, Internal Report No. 2-74/75.

5.4 Papers Completed in the Period

The following papers are soon to appear in the Proceedings, NATO Advanced Study Institute "Exploitation of Seismograph Networks", Sandefjord, April-May 1974:

Berteussen, K.A.: Array data in crustal structure research.

Berteussen, K.A., A. Christoffersson, A. Dahle and E.S. Husebye: Modelling the geological structures beneath the NORSAR array as a Chernov medium.

Bungum, H.: Analysis of multipath propagation of Rayleigh waves.

Bungum, H.: Seismic array data handling.

Dahle, A., E.S. Husebye, K.A. Berteussen and A. Christoffersson: Wave scattering effects and seismic velocity measurements.

Husebye, E.S., A. Christoffersson and C.W. Frasier: Orthogonal representation of array-recorded short period P-waves.

King, D.W.: The use of seismograph arrays in investigating the earth's deep interior.

Rieber-Mohn, D.: Aspects of ARPANET usage at NORSAR.

Rieber-Mohn, D.: Introduction to the use of terminals on the ARPA network.

Ringdal, F., E.S. Husebye and A. Dahle: P-wave envelope representation in event detection using array data.

The following papers have been submitted to and accepted by scientific journals in the United States and Europe:

Berteussen, K.A.: Crustal structure and P-wave travel time anomalies at NORSAR, Zeitschrift für Geophysik, in press.

Bungum, H., and E.S. Husebye: Analysis of the operational capabilities for detection and location of seismic events at NORSAR, Bull. Seism. Soc. Am., Vol 64, No 3, 1974.

Bungum, H., and J. Capon: Coda pattern and multipath propagation of Rayleigh waves at NORSAR, Phys. of the Earth and Plan. Int., in press.

Christoffersson, A., and E.S. Husebye: Least squares signal estimation techniques in analysis of seismic array recorded P-waves, in press.

Husebye, E.S., A. Dahle and K.A. Berteussen: Bias analysis of NORSAR and ISC reported seismic event m_b magnitudes, J. Geophys. Res., Vol 79, No 20, 1974.

Husebye, E.S., H. Gjøystdal, H. Bungum and O. Eldholm: Seismicity of the Norwegian and Greenland Seas and adjacent continental shelf areas, Tectonophysics, in press.

The following paper will appear in the Proceedings, International Symposium on Seismology and Physics of Solids of the Earth's Interior, Jena, East Germany, 1-6 April 1974:

Berteussen, K.A.: Wave scattering effects in modelling intrinsic time and amplitude anomalies observed across the NORSAR array.

5.5 Data Tapes

126 data tapes were sent to the Seismic Data Analysis Center in the reporting period.

6. REFERENCES

Aki, K., and E.S. Husebye (1974): Preliminary report on and proposal for future focal mechanism study of North Atlantic earthquakes by the surface wave method, Scientific Report No. 2-74/75, NTNF/NORSAR, Kjeller, Norway.

Aki, K., A. Christoffersson and E.S. Husebye (1974): Three-dimensional seismic-velocity anomalies in the earth's crust and upper mantle, in preparation.

Bungum, H., and F. Ringdal (1974): Diurnal variation of seismic noise and its effect on detectability, Scientific Report 5-73/74, NTNF/NORSAR, Kjeller, Norway.

Husebye, E.S., H. Gjøystdal, H. Bungum and O. Eldholm (1974): Seismicity of the Norwegian and Greenland Seas and adjacent continental shelf areas, Tectonophysics, in press.

Steinert, O., E.S. Husebye and H. Gjøystdal (1974): Seasonal and diurnal noise variance fluctuations and earthquake detectability using the NORSAR array, submitted to Zeitschrift für Geophysik.