

AD/A-005 775

PROGRESS REPORT NORSAR PHASE 3

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Royal Norwegian Council for Scientific and
Industrial Research

Prepared for:

Advanced Research Projects Agency
Air Force Technical Applications Center
VELA Seismological Center

31 January 1975

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER F08606-74-C-0049	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A005 775
4. TITLE (and Subtitle) Progress Report NORSAR Phase 3 4th Quarter 1974		5. TYPE OF REPORT & PERIOD COVERED Progress Report 4th Quarter 1974
7. AUTHOR(s) Prepared by K.A. Berteussen		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS NTNF/NORSAR Post Box 51 2007 Kjeller, Norway		8. CONTRACT OR GRANT NUMBER(s) F08606-74-C-0049
11. CONTROLLING OFFICE NAME AND ADDRESS VELA Seismological Center Attn: Capt R.J. Woodward 312 Montgomery Street, Alexandria, Va.		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 31 January 1975
		13. NUMBER OF PAGES 18
		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Reproduced by NATIONAL TECHNICAL INFORMATION SERVICE US Department of Commerce Springfield, VA. 22151		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
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 October-31 December 1974. The NORSAR Maintenance Center at Stange had a fire the 24th of November, but without serious damage to any NORSAR installations. A small increase in the number of instruments with characteristics outside tolerance limits has been observed, also some of the computer units have had several short stops due to faulty components. Except for that the performance of the field instrumentation and the computer installations has been satisfactory. A floating threshold procedure has been implemented		

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AFTAC Project Authorization No. : VT/5702/B/ETR
ARPA Order No. : 2551
Program Code No. : 5F10
Name of Contractor : Royal Norwegian Council
for Scientific and Industrial
Research
Effective Date of Contract : 1 July 1974
Contract Expiration Date : 30 June 1975
Contract No. : F08606-74-C-0049
Short Title of Work : Norwegian Seismic Array
(NORSAR) Phase 3
Amount of Contract : \$900 000.--
Date of Report : 31 January 1975
Contract Period Covered by
Report : 1 October - 31 December 1974
Project Manager : N. Marås, (02) 71 69 15

This research was supported by the Advanced Research Projects Agency of the United States Department of Defense and was monitored by AFTAC/VELA Seismological Center under Contract No. F08606-74-C-0049 with the Royal Norwegian Council for Scientific and Industrial Research.

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ABSTRACT

The report covers operation and research activities at the Norwegian Seismic Array (NORSAR) in the period 1 October - 31 December 1974. The NORSAR Maintenance Center at Stange had a fire the 24th of November, but without serious damage to any NORSAR installations. A small increase in the number of instruments with characteristics outside tolerance limits has been observed, also some of the computer units have had several short stops due to faulty components. Except for that the performance of the field instrumentation and the computer installations has been satisfactory. A floating threshold procedure has been implemented in the Detection Processor. In the Event Processor some additional statistical tests have been included as a result of a study of signal-noise classification problems. A study of precursors to PP has been finished. A power plant near 14C is producing a strong steady state noise component at this subarray. This, however, has the advantage that it can be used for monitoring in situ stress changes. Finally it has been found that autoregressive analysis of P-wave signals may be used for short period discriminants.

1. ADMINISTRATION AND ECONOMY

1.1 Personnel

Mr. H. Gjøystdal took up his work again in the Research Group 30 September after one year's leave of absence in the army.

1.2 Property

The NORSAR Maintenance Center (NMC) at Stange had a fire 24 November. Even though the wooden part of the building was completely destroyed, the NORSAR installations, which were in the part of the building made of concrete, were not seriously damaged. Only a few items of U.S. property got lost in the fire. The loss is reported to the U.S. Air Force (USAF) Property Administrator.

Technical Project Officer (TPO) Capt. Woodward has been contacted due to technical problems with an IBM Card Punch

and Tape Drives. The Card Punch will be changed if a substitute is available from U.S. Government sources.

Some excessive equipment, junction boxes, office equipment and other miscellaneous items, have been sold or disposed of during the reporting period. All actions are approved by the USAF Property Administrator.

1.3 Economy

All salaries for NORSAR personnel were raised 5% from 1 December due to a general raise in the NTN system. The raise was compensation for the inflationary price increases from 15 March - 15 November this year.

Economy Status:

1.	Operations and Maintenance		
1.1	Data Processing Center	\$ 140.888	
1.2	Field Installations	\$ 26.240	
1.3	Data Communications	<u>\$ 20.647</u>	\$187.775
2.	Research and Development		\$ 13.193
3.	Administration		<u>\$ 25.559</u>
			<u>\$226.527</u>

2. ARRAY MONITORING AND FIELD INSTALLATIONS

Compared with last quarter of 1973, the maintenance activity has been low (28 maintenance visits this quarter compared with 56 last quarter of 1973). A small increase in the number of channels with characteristics outside tolerance limits has been observed this period from six channels as of 1 October to fourteen at the end of the period. This is mainly caused by an increase in the 'trigger threshold' for maintenance visits to the subarrays in order to save manpower and funds.

The NORSAR Analog SP Station was moved to NMC 11 November. Regular operation was resumed 22 November after some problems with the timing had been solved. A report on the technical details will be issued.

The communication line connecting NORSAR Data Processing Center (NDPC) to the simulated subarray at NMC has been down since 24 November due to the fire at NMC.

2.1 NDPC Activity

An option for easy access to the model parameters at three different points in the data channels has been implemented in CHANEVSP/LP analysis programs.

A data channel response program, giving the theoretical ground displacement for a given frequency, has been completed.

2.2 Field Maintenance

The snow conditions have prevented repair of broken cables at 10C04, 05, 06. After two unsuccessful attempts, this work is postponed until the sites can be reached by snow-vehicles. In addition to routine maintenance, five short period Line Termination Amplifiers have been replaced due to presampling filter faults. One short period seismometer (02C02) was replaced 5 December as the damping and natural frequency were outside the tolerance limits.

3. COMPUTER CENTER OPERATION AND DATA PROCESSING

3.1 Data Center Operation

No single long-duration machine stops occurred in the period. The various down times in the table below are accounted for by several short stops due to faulty components, power failures and scheduled maintenance. Tapes and tape

drives caused some concern as excessive data-checks occurred. Rewinding/cleaning of stored tapes before (re)use was started in November. This, together with an intensified tape drive check program, seems to have had a corrective result.

Total DP non-recording time in the quarter:	16 hours (0.7%)
SPS down time	16 hours (0.7%)
A Computer down time	16 hours (0.7%)
B Computer down time	28 hours (1.25%)

Average communication line down time (22 lines) 14 hours (0.64%).

The Trans-Atlantic and London links performed satisfactorily with 1 and 3 registered short breaks respectively.

The ARPANET Terminal Interface Processor (TIP) was routinely restarted 7 times in the period.

Approximately 3400 job shop programs were run.

3.2 Programming Efforts

The following programs were developed in this period:

- a program computing the phase and normalized amplitude of the theoretical NORSAR short or long period data channel ground displacement response, for a given frequency
- a set of programs performing Data Retention on the NORSAR Low Rate tapes
- a set of subroutines to facilitate the use of disk pack extents as intermediate storage for FORTRAN jobs
- a program for computing autoregressive coefficients of power spectral estimates.

Also, a program that selects earthquakes from the CGS bulletin tapes has been adapted to NORSAR processing environments. The 4th edition of the IMSL Library 1 (International Mathematical and Statistical Libraries, Inc.) has been received and implemented.

3.3 Detection and Event Processing

A floating threshold procedure has been implemented in the Detection Processor. The current value of the noise stability, computed continuously, is transmitted to the Shared Disk Pack Signal Arrival File with each coherent detection.

In the Event Processor (EP), the noise stability (STAB) received from the Detection Processor via the Shared Disk pack Signal Arrival File entries, is used together with a desired false alarm rate (FAR), inserted by the operator at startup time, to compute a time-varying pre-threshold value for the signal-to-noise ratio of the coherent detections. The formula used is:

$$TH(dB) = 12.08 - 0.89 \cdot \log(FAR) - 0.18 \cdot STAB$$

A new value of this pre-threshold is computed each time the value of the stability changes. The actual computation takes place in a separate FORTRAN overlay phase, loaded by the EP controller each time it is used. Based on two weeks of operation in December, we can already conclude that the floating threshold procedure has been successful. The number of false alarms in EP is now practically constant, regardless of noise condition, and this first of all means more efficient data handling, probably also a few more events. It remains to see how the procedure works for extremely low noise levels, i.e., high stability.

A new package has been implemented in EP. It will be executed for coherent detections with signal-to-noise ratios in an interval just above the (time-varying) pre-threshold. Depending on the significance of a statistical test, calculation of optimum subarray beam weights, and a subsequent array beamforming with these weights, is performed. Two additional statistical tests are performed. The results of all the three tests and the optimum weights are printed in the Summary Report for each event, to aid the analyst in his decision. Also, the optimally weighted array beam is plotted on the event's plot panel. Three weeks of operation in December has shown that the package is useful in identifying doubtful events. However, it seems difficult to circumvent the basic problem that signals and very "unlikely" noise wavelets overlap in statistical properties. Further evaluation will be concentrated on the use of the computed subarray weights in relation to the known weights for any particular seismic region.

3.4 The NORSAR Terminal Interface Message Processor (TIP) Connection

The use of the ARPANET terminal attachment from NORSAR in this quarter does not differ from earlier reported use. It consists of the following:

- Routine transmission of the NORSAR bulletin to the message file of the U.S. Geological Survey on the OFFICE-1 computer at Stanford
- Information exchange with Seismic Data Analysis Center (SDAC), Lincoln Laboratory's Seismic Discrimination Group, and other institutions more sporadically. This activity is based on our account on the SRI-ARC (Stanford Research Institute's Augmentation Research Center) computer and the use of its facilities and resources.

Other agencies than the USGS have lately shown an interest in accessing our bulletin via the ARPANET. One way to do this, preventing extra work, would be to store our bulletins as files on some Host computer in the network, and make these accessible to interested parties. A positive side effect of this arrangement would be easier internal management (creation, updating, sorting) of the bulletins.

The specification of the special high level protocol for data exchange between the SDAC Communications and Control Processor and a Site was received in October. A study has been initiated for the purpose of arriving at design specifications for the on-line Network Control Program, subject to the constraints of the protocol and the Detection Processor environment.

4. RESEARCH AND DEVELOPMENT

A study of statistical methods to use in signal-noise classification problems has resulted in some additional tests implemented in the Event Processor. A study of precursors to PP has been finished. A power plant near 14C is producing a strong steady state noise component at this subarray. This, however, has the advantage that it can be used for monitoring in situ stress changes. Finally it has been found that autoregressive analysis of P-wave signals may be used for short period discrimination.

4.1 Signal-Noise Classification

Three statistical tests, Sign-Bit Semblance, Binomial and Student's t-test (Fyen et al, 1974) have been evaluated to test the hypothesis whether a wavelet triggering the event detector has its origin in a real earthquake or not. Sign-Bit Semblance measures the signal similarity across the array. Binomial and Student's t-test are computed from

optimum amplitude weights, which are an estimate of the amplitude factor, γ_j , in the model $Y_j = \gamma_j S + n_j$, where Y_j is the recorded data on the j -th sensor, S a signal part and n_j a noise part. For noise wavelets, the amplitude weights will be random in sign and size, while for P-waves the $\hat{\gamma}_j$ -weights match the amplitude pattern in the region in question. However, for events with a signal-to-noise ratio as small as 3.6-4.0 units, the $\hat{\gamma}_j$ -weights contain reliable amplitude information for the "best" subarrays only, and the correspondence between the observed $\hat{\gamma}_j$ -weights and the known amplitude pattern for larger earthquakes is small, a problem which will be investigated further. Also for some extreme cases, noise has the same characteristics as an earthquake signal, as seen in Fig. 4.1 where the best statistics accepted the event, but these cases may be eliminated by the analyst due to his experience of earthquake occurrence and signal shape. As noted in section 3.3, the test statistics are included in the Event Processor, which will give more experience in the use of the tests as signal-noise discriminants.

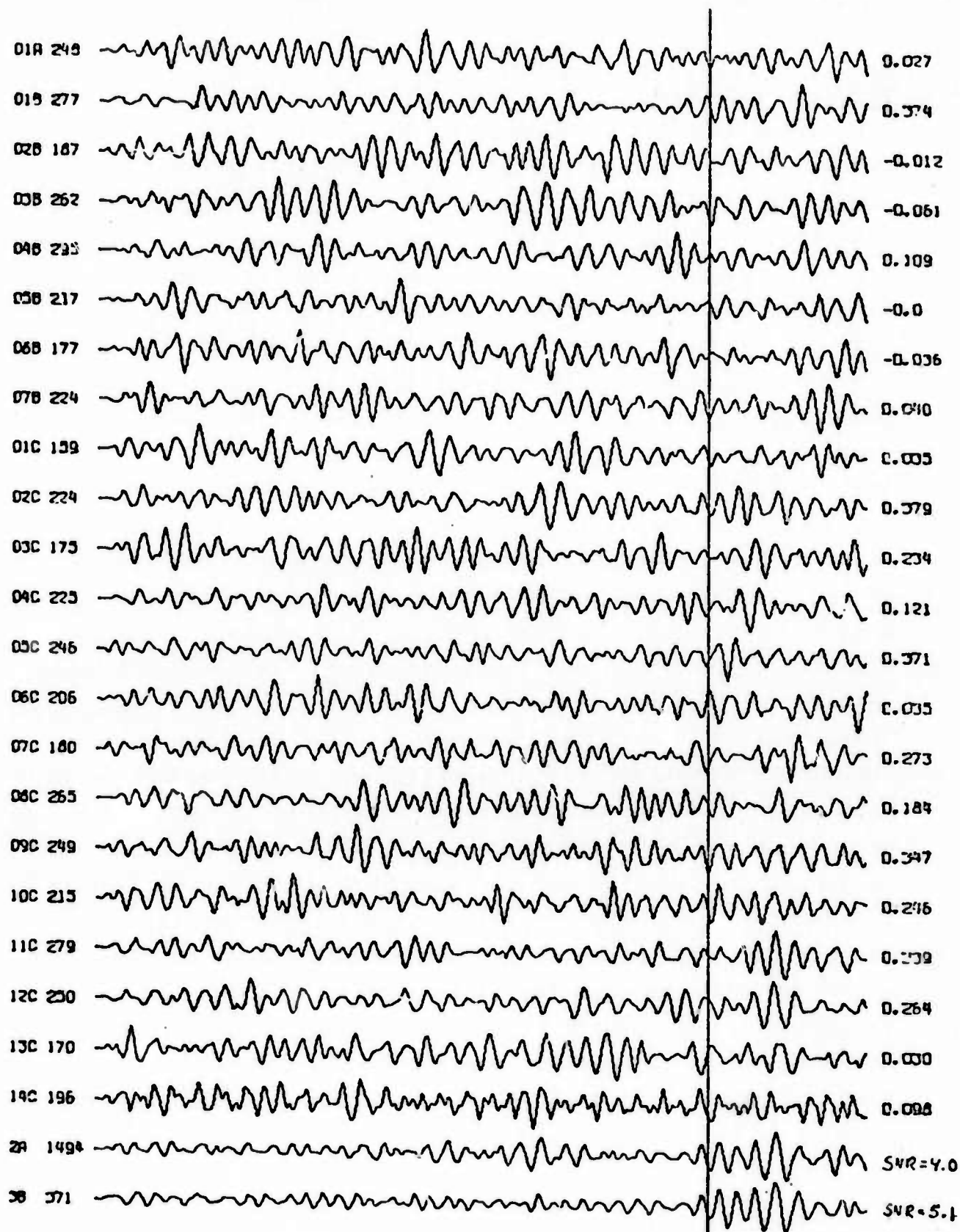


Fig. 4.1 Example of extreme noise wavelets. The column to the right gives the $\hat{y}_j$ -weights. 2A and 3B denote array and weighted array beam respectively, pointing south of Honshu, Japan. The test results give high signal similarity and non-random sign and size of the amplitude weights, but a check with the amplitude pattern rejects this event as being an earthquake in Japan area.

4.2 Precursors to PP

A detailed study of precursors to PP has been completed. Extensive observational data from the NORSAR and Warra-munga arrays has been analysed, and power within precursor wave trains has been mapped as function of time, slowness and azimuth. An example of the PP precursors at NORSAR from an event in the Molucca Passage ($\Delta \sim 100^\circ$) is shown in Fig. 4.2, and the power distribution in azimuth for a travel time of 1025 sec is illustrated in Fig. 4.3. The observed power variations for a wide range of travel times have been compared with the results of a theoretical study of the interpretation of PP precursors in terms of scattering by small-scale random irregularities in the crust and uppermost mantle. This comparison revealed that the scattering interpretation offers a plausible and adequate explanation of the detailed observational data, namely: onset times, duration, slowness, azimuth and amplitude variations. The correspondence between observed values and those predicted on the scattering interpretation is evident from Fig. 4.3, in which theoretical curves for $T=1025$ secs and two different upper mantle models have been included. The scattering interpretation of PP precursors has an important bearing on the interpretation of the entire short period teleseismic P coda, and, moreover, removes the need for postulating sharp reflecting discontinuities in the uppermost few hundred kilometers of the crust and upper mantle. This latter conclusion is also supported by the results of a similar study of precursors to PKPPKP which is nearing completion. This work has been undertaken by D.W. King, R.A.W. Haddon and E.S. Husebye.

— TIME (MINUTES) —

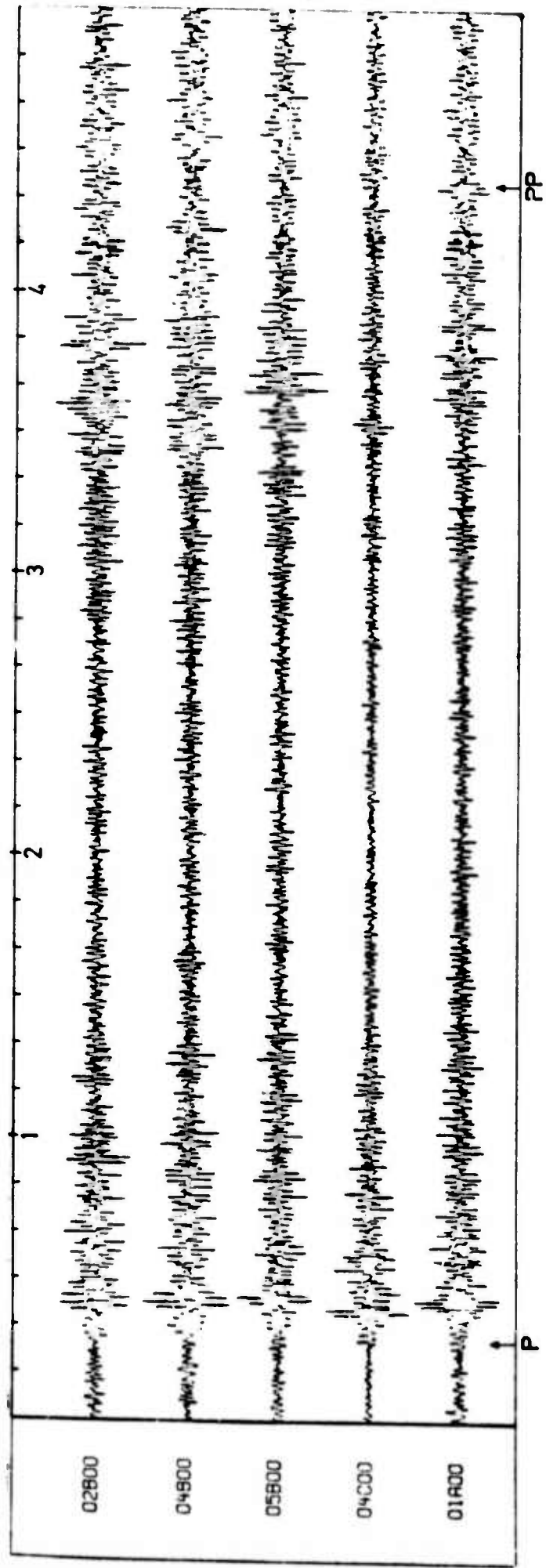


Fig. 4.2 Seismogram from 5 NORSTAR subarray central instruments (as labelled) for an event in the Molucca Passage ($\Delta=100^\circ$). The data has been filtered in the range 0.6 Hz to 3.0 Hz. Note the extended PP precursor wavetrain starting at about 2 mins 50 secs.

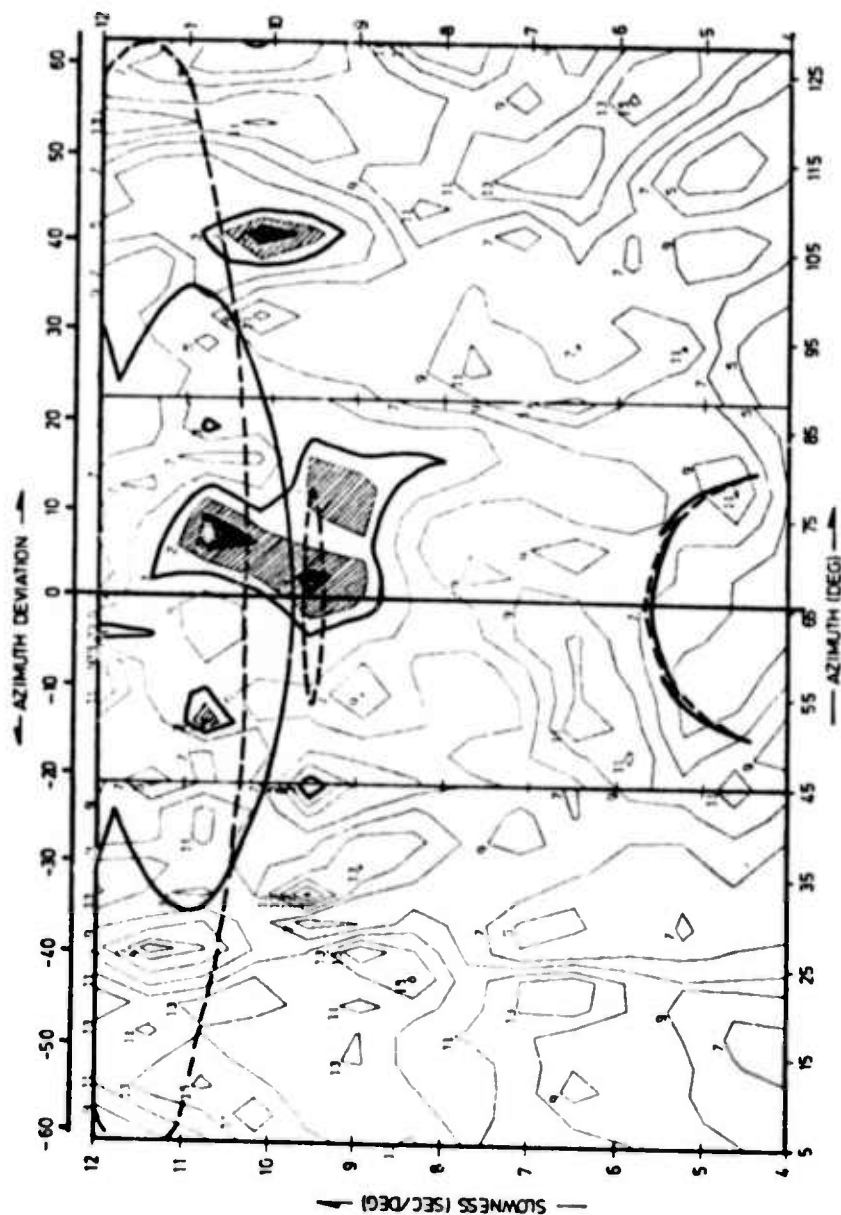


Fig. 4.3 Contoured beam power (p) values averaged over 3 seconds at travel time 1025 sec for the event in Fig. 4.2. The 3 dB contour is darkened, and enclosed power values are hatched ($2 \text{ dB} < p < 1 \text{ dB}$) and dotted ($1 \text{ dB} < p < 0 \text{ dB}$). Theoretical results for $T=1025 \text{ sec}$ and $\Delta=100^\circ$ for the Jeffreys model (solid line) and SMAK II model (broken line) are plotted for comparison with the observed power distribution. Note the wide azimuthal spread of power at high slownesses.

4.3 In Situ Stress Monitoring

For some years now, the existence of narrow spectral peaks in the NORSAR short period recordings has been known and investigated. Several such peaks have been found and identified to have their origin in hydroelectric power plants, although some remain to be explained (Hjortenberg and Risbo, 1974).

A power plant near 14C has been found to generate a very strong spectral component at 2.78 Hz, corresponding to 166 2/3 rpm. This is now being used as a steady state energy source for possible monitoring of in situ stress changes. The six short period seismometers in 14C have a distance from the source ranging from roughly 2 to 12 km, and the analysis is done through a spectral analysis giving phase differences between stations. Fig. 4.4 gives an example where all station combinations have been plotted, and the value for each one is repeated for every 2π because the number of full wavelengths is not known. There appears to be a lineation corresponding to 5 km/sec which is a reasonable velocity for the distances involved in this experiment.

Using 15 minutes of night time data, spectral estimates have already been obtained with a phase angle stability of $\pm 2^\circ$, which corresponds to a precision of about 10^{-3} . The main restrictions here are the stability of the instruments (which is very good) and the signal-to-noise ratio. By adding more data, and possibly by inserting a clean reference signal at 2.78 Hz in one of the channels, we hope to be able to increase the precision to about 10^{-4} , which is very good for such large distances and about the level at which earth tides should be observed. This work has been undertaken by K. Aki and H. Bungum.

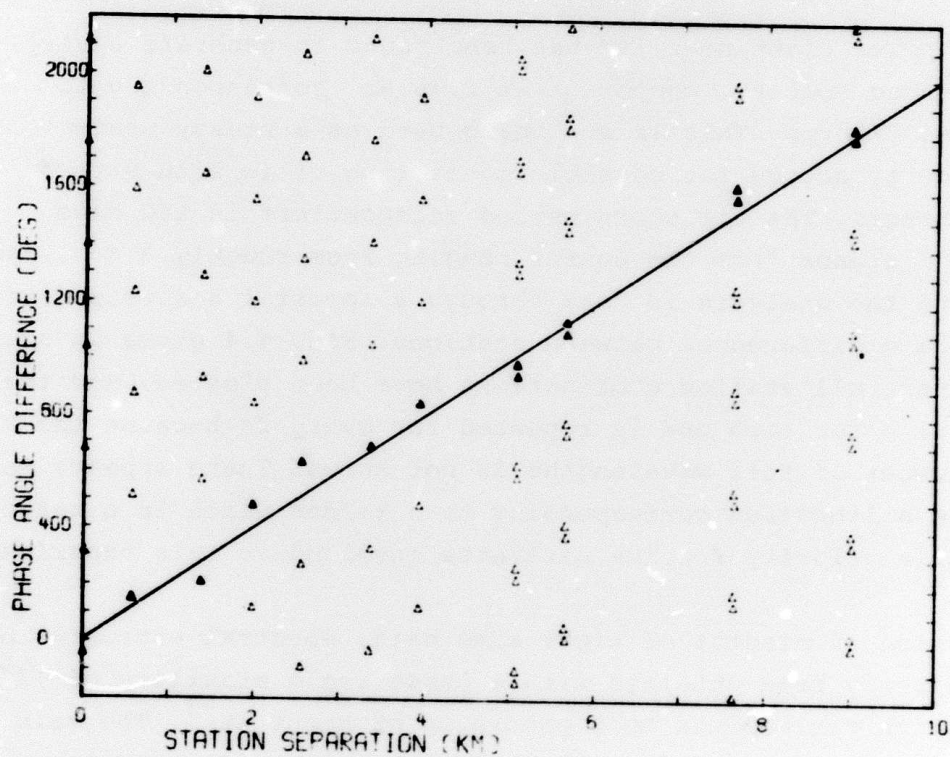


Fig. 4.4 Phase angle differences vs. station separation for the 2.78 Hz spectral component at 14C, plotted at intervals of 360° . The straight line corresponds to a velocity of 5.0 km/sec.

4.4 Autoregressive Analysis of Seismic P-wave Signals and Short Period Discrimination

A new short period discriminant between earthquakes and underground nuclear explosions has been constructed. The discriminant is based on second order statistical properties of seismic P-wave signals. It is shown that the digitized time series defined by a seismic P-wave signal can be split into several sections, each of which is described statistically by a lower order (order varying from 2 to 6 in most cases) autoregressive model. An autoregressive model has the form

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

where $X(t)$ is the short period data time series defined by the P-wave signal, $Z(t)$ is a white noise time series and p is the order of the model. The autoregressive representation of the signal has the advantage of concentrating the power spectrum information into a few autoregressive parameters. The autoregressive analysis was carried out for 40 underground nuclear explosions and 45 earthquakes from Eurasia. A plot of the two most significant autoregressive coefficients is given in Fig. 4.5. At a later stage it is our objective to examine the performance of multivariate discriminants constructed by combining autoregressive parameters with existing discriminants. This work has been undertaken by D. Tjøstheim.

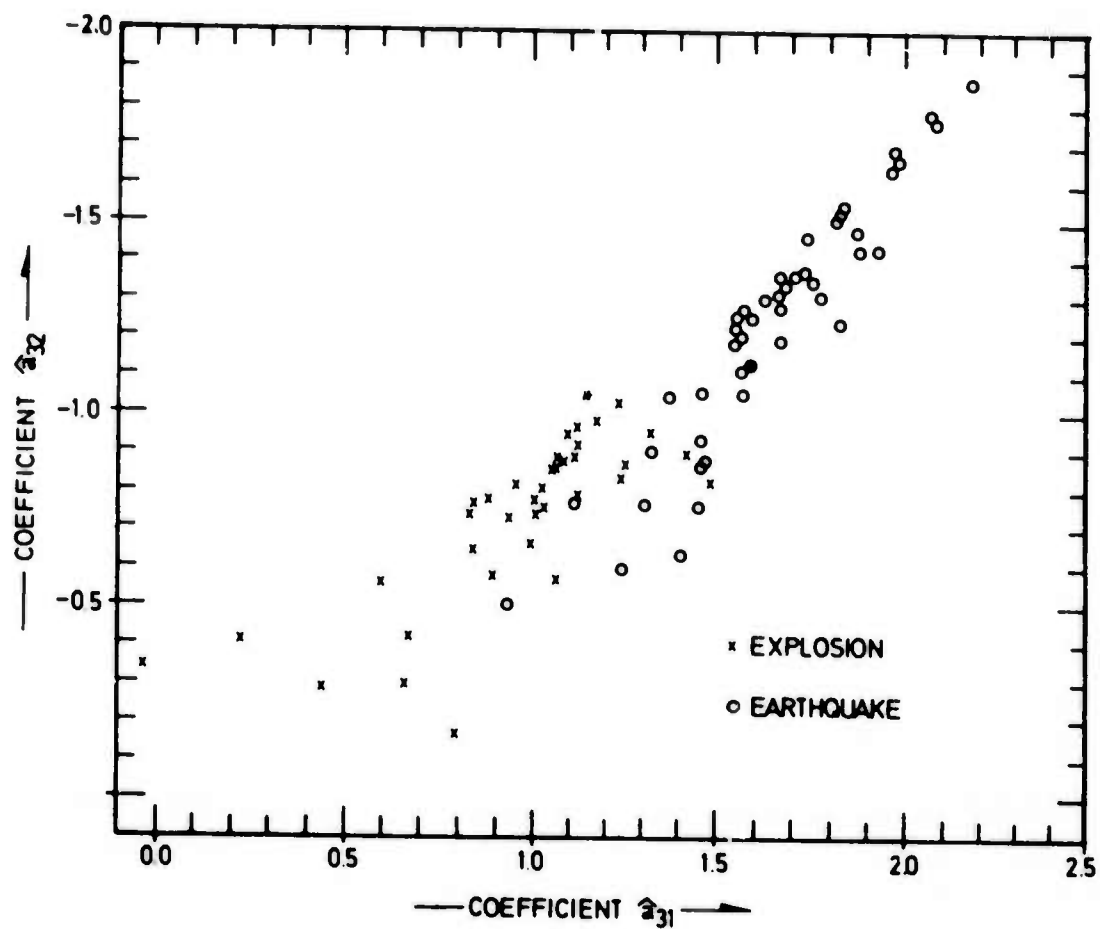


Fig. 4.5 Estimated coefficients $\hat{a}_{31}$ and $\hat{a}_{32}$ assuming a 3rd order autoregressive model.

$$X(t) - a_{31} X(t-1) - a_{32} X(t-2) - a_{33} X(t-3) = Z(t).$$

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. S. Gregersen and Dr. E. Hjortenbergh, Dept. of Geodetics,
University of Copenhagen, 15 - 25 October 1974

Lt. Col. N. Orsini and Capt. R.J. Woodward, 22 - 24 October
1974

Professor Berckhemer, Institut für Meteorologie und Geophysik,
Frankfurt, West Germany, 16 November 1974

Dr. Seppo Pirhonen, University of Helsinki, 9 - 20 December
1974

Dr. Heikki Korhonen, University of Oulu, Finland,
13 - 20 December 1974.

5.2 Doctoral Thesis

On 15 November 1974 Hilmar Bungum successfully defended his Doctoral Thesis, Detection, Location and Identification of Seismic Events Using the Norwegian Seismic Array, at the University of Bergen.

5.3 Reports Completed

Berteussen, K.A., and E.S. Husebye: Amplitude Pattern Effects on NORSAR P-wave Detectability, NORSAR Scientific Report 1-74/75.

Berteussen, K.A.: Progress Report, 3rd Quarter 1974.

5.4 Papers Presented

The paper "Three dimensional seismic-velocity anomalies in the crust and upper-mantle under the U.S.G.S. California seismic array" by K. Aki, E.S. Husebye, A. Christoffersson and C. Powell was presented by K. Aki at the Annual Fall Meeting of the A.G.U. in San Francisco in December.

5.5 Data Tapes

87 data tapes were sent to the Seismic Data Analysis Center in Alexandria, Virginia, in the fourth quarter of 1974.

6. REFERENCES

Fyen, J., E.S. Husebye and A. Christoffersson (1974): Signal-noise classification, in press.

Hjortenbergh, E., and T. Risbo: Monochromatic components of the seismic noise in the NORSAR area, submitted to Geophys. J.R. Astr. Soc.