# NORSAR

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Scientific Report No. 4-73/74

# SEMIANNUAL TECHNICAL REPORT
# NORSAR PHASE 3

1 July–31 December 1973

Prepared by
Hilmar Bungum
(Editor)

Kjeller, 11 January 1974

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | | |
|---|---|---|
| 1. REPORT NUMBER<br>F44620-74-C-0001 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (*and Subtitle*)<br>Semiannual Technical Report - NORSAR Phase 3<br>1 July - 31 December 1973 | | 5. TYPE OF REPORT & PERIOD COVERED<br>Scientific Report<br>6. PERFORMING ORG. REPORT NUMBER<br>Sci.Rep. No. 4-73/74 |
| 7. AUTHOR(*s*)<br>H. Bungum (editor) | | 8. CONTRACT OR GRANT NUMBER(*s*)<br>F44620-74-C-0001 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>NTNF/NORSAR<br>Post Box 51<br>N-2007 Kjeller, Norway | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>NORSAR Phase 3 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Air Force Office of Scientific Research<br>1400 Wilson Blvd<br>Arlington, Virginia 22209, U.S.A. | | 12. REPORT DATE<br>11 February 1974<br>13. NUMBER OF PAGES<br>75 |
| 14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)<br>European Office of Aerospace Research and Development<br>223/231 Marylebone Road, London NW1 5TH<br>UNITED KINGDOM Attn: Maj. F.D. Munzlinger | | 15. SECURITY CLASS. (*of this report*)<br>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*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

NORSAR, seismic array, seismology

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

This is the first in a series of Semiannual Technical Reports from NTNF/NORSAR. The activity in this reporting period is characterized by a continued concentration of research on short period data, and some work utilizing long period data. The physical operation of the array is characterized by stability.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

| | | |
|---|---|---|
| USAF Project Authorization No. | : | VT/4702/B/OSR |
| Date of Contract | : | 30 August 1973 |
| Amount of Contract | : | $ 888,806.00 |
| Contract Termination Date | : | 30 June 1974 |
| Project Supervisor | : | Robert Major, NTNF |
| Project Manager | : | Nils Marås |
| Title of Contract | : | Norwegian Seismic Array (NORSAR) |

TABLE OF CONTENTS

ABBREVIATIONS (Chapters P and Q)

| | | |
|---|---|---|
| ADC | - | Analog-to-Digital Converter |
| AM | - | Array Monitoring |
| BB | - | Broad Band |
| BE card | - | Lightning Protection Card |
| CMR | - | Common Mode Rejection |
| CTV | - | Central Terminal Vault |
| DI | - | Discrete Input/SLEM |
| DU | - | Digital Unit |
| EPU | - | External Power Unit/SLEM |
| EW | - | East West horizontal LP component |
| FM | - | Frequency Modulation |
| FP | - | Free Period |
| Ithaco | - | LP Seismograph Amplifier |
| LP | - | Long Period |
| LPV | - | LP Sensor Vault |
| LTA | - | Line Termination Attenuator |
| MP | - | Mass Position |
| MUX | - | Multiplier/SLEM |
| NDPC | - | NORSAR Data Processing Center |
| NMC | - | NORSAR Maintenance Center (Stange) |
| NS | - | North South horizontal LP component |
| NTA | - | Norwegian Telegraph Administration |
| ODW | - | Output Data Word |
| RA-5 | - | SP Seismograph Amplifier |
| RCD | - | Remote Centering Device |
| RSA | - | Range Scaling Amplifier |
| SLEM | - | Short and Long Periodic Electronic Electronic Module |
| SP | - | Short Period |
| WHV | - | Well Head Vault |
| | - | |

SUMMARY

This is the first in a series of Semiannual Technical Reports from NTNF/NORSAR. The activity in this reporting period is characterized by a continued concentration of research on short period data, and some work utilizing long period data. The physical operation of the array is characterized by stability.

It is now about three years since the first experimental operation of the full NORSAR array commenced. This initial period required intensive efforts in completing and improving the software for the routine operation, compiling and implementing the correction and calibration data, and getting acquainted with the data from the different seismic regions of the world. The research work at NORSAR so far has been aimed at these objectives, i.e., to improve the operational performance of the array and to investigate the various limitations involved. As part of this, a full year of data (April 72 - March 73) have been extensively analyzed in order to, on a regionalized basis, determine the capability of the array to detect and locate seismic events. The results essentially show that Central Asia is the region in which the best performance of the NORSAR array is obtained. In a separate study, the effect of the systematic time delay and slowness anomalies on this capability have been investigated, with the conclusion that the corrections used today are close to optimal. Another problem in this evaluation has been the use of the magnitude scale; it has been demonstrated that there is no simple relationship between the $m_b$ values from different stations or agencies. As part of the evaluation of NORSAR, prognosis models are set up describing the relationship between NORSAR and NOAA $m_b$ for different

regions. In a separate study, comparisons with ISC magnitudes are made, and both the ISC and the NORSAR $m_b$ values are investigated for the possibility of internal bias.

It has been mentioned that time delay anomalies are now effectively corrected for in the NORSAR detection processing. An entirely different problem is the physical explanation for these deviations, where several efforts have been made over the past few years to set up models of the crust and upper mantle, as well as the source regions, which could account for the observed time anomalies. The problem has been investigated at NORSAR from a slightly different point of view, and it was found that physically realistic models of the crust-upper mantle interface (or any other interface) could explain only 25% of the deviations. It thus seems that other models have to be introduced where for example wave scattering effects play a more important role. In fact, the latter phenomenon has been investigated in view of the Chernov theory for wave propagation in random media. In one study 33 events and 54 seismometers were used, and it was found that the scattering was too strong for the Born approximation to be fulfilled, especially for high frequencies. Secondly, observed time delays were explained through a model including besides the standard deterministic term, a stochastic scattering effect. In this way, the residual variances could be reduced by more than 50% relative to a deterministic model. Finally, in two different studies precursor waves of P'P', PKP and PKKP have been analyzed from the point of view of wave scattering, where theories have been forwarded which seem to be able to explain most of the observed large deviations in azimuth and slowness.

Large azimuthal deviations are also observed for surface waves, as demonstrated in a special study of Rayleigh waves from 15 events recorded at NORSAR. Lateral refraction and reflection is assumed to account for most of the observed multipathing. In another, entirely different study from those above, seismicity data for the Greenland and Norwegian Seas have been compiled and interpreted in the light of our present knowledge of the evolution of these areas.

In the last seven chapters of this report, various aspects of the fairly complex job of keeping NORSAR in operation, with as high standards as possible, have been reported on. The running of the Detection and Event Processors is an essential part of this, and that job is not a routine one. Among other things, it requires continuous attention from the Programming Group, a "pool" which can report on a wide range of activities. One of these is the new ARPANET connection, which connects NORSAR to a large number of computer installations in the U.S.A., and which open new possibilities for international data exchange. An important part of the activities at NORSAR is the actual physical operation of the installation and the maintenance required in order to keep top standards. Two groups are covering this work, which is reported on in the last two chapters.

H. Bungum

# A. EVENT DETECTION AND LOCATION CAPABILITIES AT NORSAR

A fairly extensive study has recently been completed on the operating capability of NORSAR to detect and locate seismic events (Bungum & Husebye 1974). This is based on one year of data, from April 1972 through March 1973. Before this period, several important changes had been introduced to the processing system, improving the performance considerably.

The detectability was investigated through the estimation of 50% and 90% detectability thresholds as derived from frequency-magnitude distributions. The basic results are given in Table A1, which shows that the best results are found for events in Central Asia and adjacent regions, where the 90% cumulative detectability values are in the range 3.6-3.8 NORSAR $m_b$ values. The most difficult areas to cover are the Mid-Atlantic ridge and America. A fairly extensive analysis of the relationship between NORSAR and NOAA $m_b$ values was also undertaken, and some results for the distance ranges $30^o$-$90^o$ and $110^o$-$180^o$ are given in Fig. A1. The relationship should be viewed first of all as a prognosis model, showing that given an event with NORSAR $m_b$ below 4.0, NOAA will most likely have a smaller magnitude. For events above 4.0, NORSAR reports in average a smaller magnitude than NOAA.

The location accuracy has also been investigated, and Table A1 here shows that the best location capability is generally found in areas with the best detectability. The best results are obtained for Japan and Central Asia, where the median location accuracy is 95 and 105 km, respectively. Further improvements are hardly possible, as biased errors in the location estimates are now insignificant (see Chapter B).

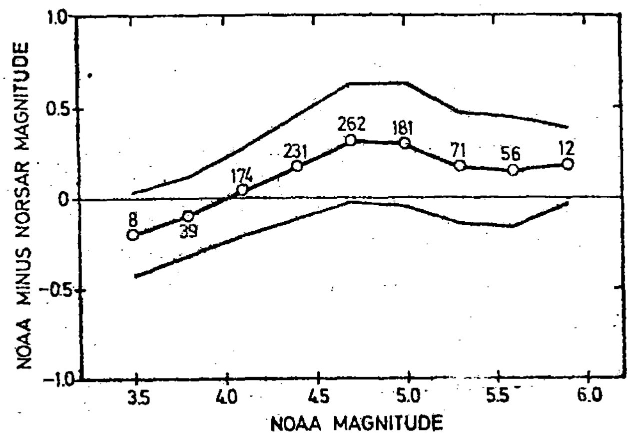
H. Bungum
E.S. Husebye

TABLE A1

Estimates of NORSAR event detectability and location capability based on data from one year of regular operation. A dash indicates that not enough data was available.

| Region | Area of Coverage | Detectability ($m_b$) | | Location Diff. (km) | |
|---|---|---|---|---|---|
| | | 50% | 90% | 50% | 90% |
| 1 | Aleutians-Alaska | - | - | 135 | 330 |
| 2 | Western North America | - | - | 185 | 310 |
| 3 | Central America | 3.7 | 4.1 | 430 | 830 |
| 4 | Mid-Atlantic Ridge | - | - | 360 | 790 |
| 5 | Mediterranean-Middle East | 3.1 | 3.7 | 220 | 650 |
| 6 | Iran-Western Russia | 3.4 | 3.8 | 150 | 580 |
| 7 | Central Asia | 3.2 | 3.6 | 105 | 270 |
| 8 | Southern-Eastern Asia | - | - | 130 | 340 |
| 9 | Ryukuo-Philippines | 3.7 | 4.2 | 195 | 610 |
| 10 | Japan-Kamchatka | 3.4 | 3.8 | 95 | 260 |
| 11 | New Guinea-Hebrides | - | - | 380 | 1330 |
| 12 | Fiji-Kermadec | 3.4 | 3.9 | 310 | 910 |
| 13 | South America | - | - | 390 | 680 |
| 14 | Distance Range $30^\circ$-$90^\circ$ | 3.4 | 3.8 | 145 | 490 |
| 15 | Distance Range $110^\circ$-$180^\circ$ | 4.0 | 4.5 | 320 | 1020 |

(a)




(b)

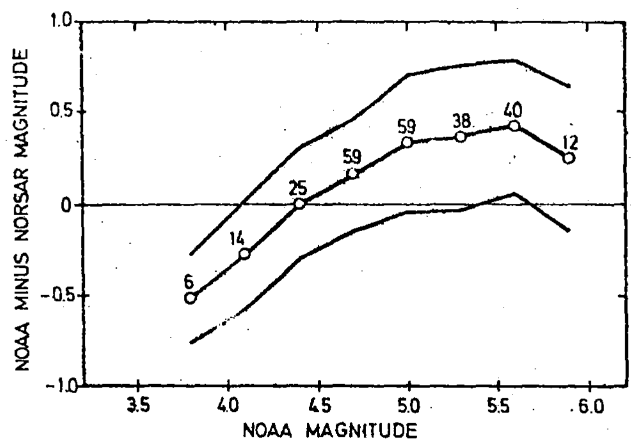



Fig. A1 Average difference between NOAA and NORSAR $m_b$ values as a function of NOAA $m_b$ for the distance range $30^\circ$-$90^\circ$ (a) and $110^\circ$-$180^\circ$ (b). Number of events and standard deviations are indicated.

## REFERENCES

Bungum, H., and E.S. Husebye: Analysis of the operational capabilities for detection and location of seismic events at NORSAR, Bull. Seism. Soc. Am., in press, (June 1974).

B. THE EFFECT OF THE SLOWNESS AND TRAVEL TIME ANOMALIES ON ARRAY PERFORMANCE

The current data base of the NORSAR location calibrations and time delay corrections were implemented 30 November 1972 (Berteussen 1974). An analysis of the influence of these on the NORSAR event location and detection capabilities has been made.

On Fig. B1 the cumulative distribution of the length (measured in real space) of the location calibration vectors for P-phases is plotted. The 90 per cent level is 1100 km while the median is 450 km. For the period from April 1972 until March 1973 Bungum and Husebye (1974) have reported a median location difference between NOAA and NORSAR epicenter solutions of 145 km for P-phases, while the 90 per cent level was 490 km. Without calibrations the location errors thus would be something like a factor of three greater.

The SNR gain from applying regional corrections and location calibrations has been calculated by analyzing 479 events randomly selected in the period November 1972 until September 1973. The results obtained are presented in Fig. B2. It is seen (curve I) that if no time delay corrections are used, 10 per cent of the events would have a loss of 0.7 dB or less while 10 per cent would have a loss of 9.5 dB or more in DP. The median for this data set is 4.5 dB and the mean value is 5.2 dB. Based on Steinberg's formula (Steinberg 1965) the theoretical expected mean value is found to be 5.3 dB.

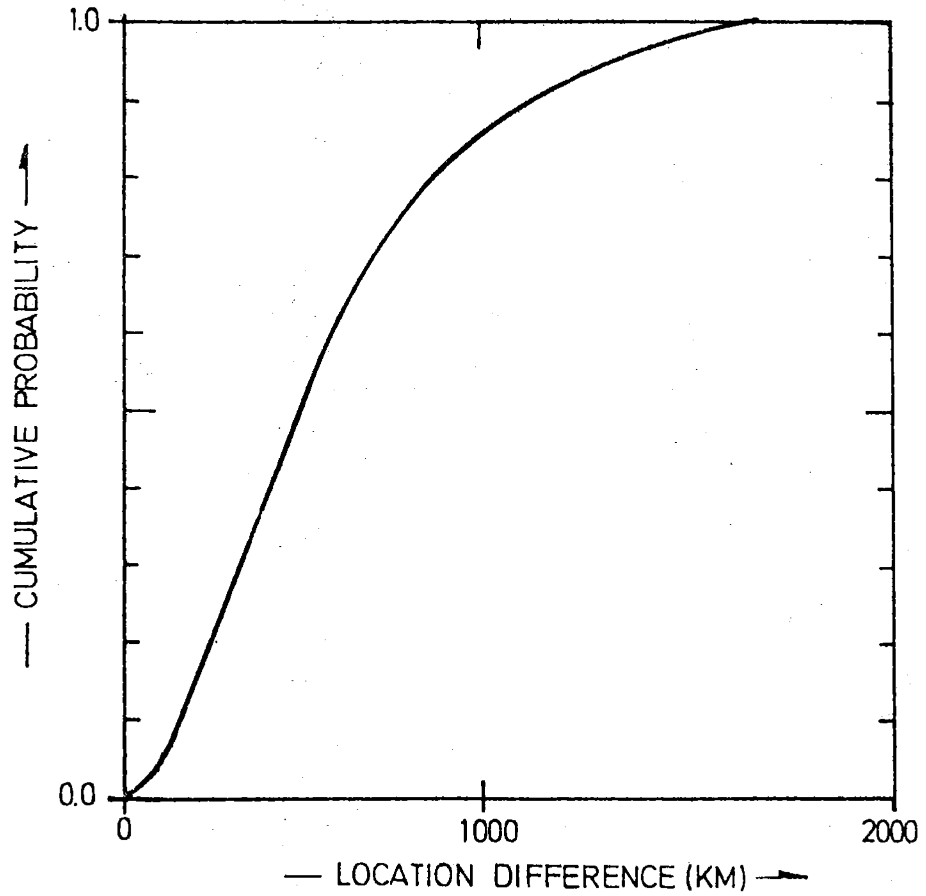



Fig. B1 Cumulative distribution of the length of the location calibration vectors transformed into real space. Only P-phase data are used.

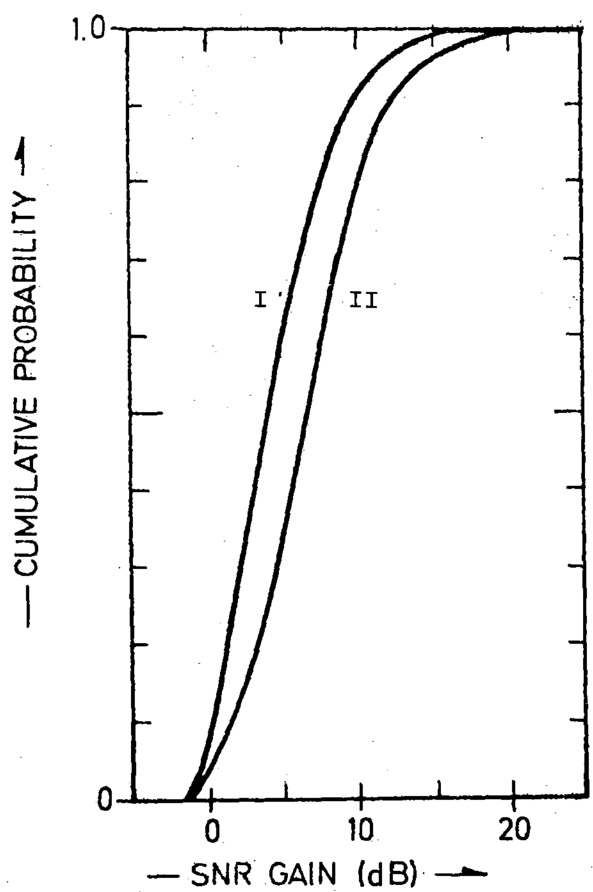



Fig. B2 Cumulative distribution of signal-to-noise (SNR) gain in DP. Curve I is for region corrections only, while Curve II gives the gain distribution when both region corrections and calibrations are applied.

The distribution of the loss in SNR between the beam the particular event was detected on in DP and the beam DP would have used if neither time delay corrections nor location calibrations had been available is plotted in curve II, Fig. B2. The 90 per cent value here is 12.5 dB, the median is 6.8 dB, while the mean is 7.4 dB. The location calibrations alone thus seem to give an SNR gain which in average is 7.4-5.2=2.2 dB. Based on the mean length of the location calibration vectors and the response pattern of the array, this value is theoretically expected to be approximately 3.0 dB.

The conclusion is thus that both the regional time delay corrections and the location calibrations are close to optimal.

K.A. Berteussen

REFERENCES

Berteussen, K.A.: NORSAR location calibrations and time delay corrections, NORSAR Scientific Report No. 2-73/74, NTNF/NORSAR, Kjeller, Norway, 1974.

Bungum, H., and E.S. Husebye: Analysis of the operational capabilities for detection and location of seismic events at NORSAR, Bull. Seism. Soc. Am., in press, 1974.

Steinberg, B.: Large aperture teleseismic array theory, ARPA report of first LASA systems evaluation conference,

## C. INVESTIGATIONS OF POSSIBLE BIAS IN $m_b$ MAGNITUDE MEASUREMENTS

The $m_b$ magnitude parameter, measured on records of short period waves, is a convenient and widely used tool for ranking of earthquakes. The problem of a possible bias in the NORSAR estimation procedure of $m_b$ magnitudes and also that used by the International Seismological Centre (ISC) in Edinburgh have been investigated.

TABLE C1

Estimated magnitude biases due to subarray power loss and skewed maximum power distribution, conditioned on the number of subarrays. The latter parameter represents a decreasing ordering of subarrays based on maximum power ranking.

| No. of Subarrays | dm(loss) ($m_b$-units) | dm(skew) ($m_b$-units) |
|---|---|---|
| 3 | 0.28 ± 0.06 | 0.0 ± 0.01 |
| 6 | 0.23 ± 0.05 | -0.01 ± 0.01 |
| 9 | 0.20 ± 0.04 | -0.02 ± 0.01 |
| 12 | 0.16 ± 0.04 | -0.03 ± 0.02 |
| 15 | 0.14 ± 0.04 | -0.04 ± 0.02 |
| 18 | 0.11 ± 0.03 | -0.05 ± 0.03 |
| Operational $19 \leq No \leq 22$ | 0.08 ± 0.03 | -0.07 ± 0.03 |
| Estimated skewness of subarray max. power distribution | | 1.26 ± 0.63 |
| Estimated skewness for log-transformation of max. power | | -0.10 ± 0.42 |
| Correlation between signal loss and skewness effects | | -0.40 corr. units |
| Sample size | | 222 events |

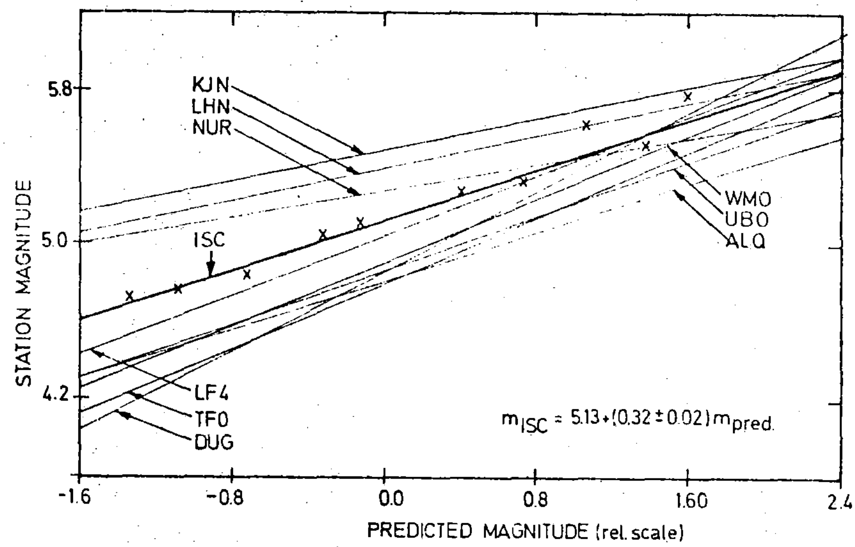



Fig. C1 Comparison between event magnitudes as predicted from a multivariate analysis of ISC data for Japan, and that of the individual stations used in the analysis. The relationship between ISC reported magnitudes and predicted magnitude is also given. Dots are observed points for this line. This figure is based on 40 events occurring in the Japan region in 1968 and reported jointly by the 9 stations listed on the figure.

The signal energy losses observed during NORSAR P-wave beamforming do not affect its event magnitude estimates due to a skew, approximately lognormal, P-amplitude distribution across the array (see Table C1). Using a linear prognosis model for checking the NORSAR-NOAA magnitude relationship, we found that for most regions the regression coefficients were significantly different from 1.0. In other words, the magnitude correction cannot be considered a constant, but depends on event magnitude and source region.

A multivariate analysis of ISC data for Japan and the Aleutian Islands gave a consistent and linear relationship between the ISC event magnitude and that predicted from subsets of 5-9 stations in the $m_b$ 4.0-6.0 magnitude range investigated. In this respect the ISC reported magnitudes are considered unbiased. We also found that the magnitude observations may be approximated by a normal distribution which corresponds to a lognormal amplitude distribution.

In the analysis of the ISC data, a linear physical model was used, i.e., the relationship between individual station magnitude and true event magnitude. It is here interesting to note that for the Japan region the regression coefficients were significantly different from each other (see Fig. C1), i.e., the magnitude correction is a function of event magnitude even when physical models are used in the magnitude analysis. This phenomenon is quantitatively explained as the combined effect of the seismic spectra scaling law and the frequency dependent crust-upper mantle transfer function.

E.S. Husebye
A. Dahle
K.A. Berteussen

REFERENCES

Husebye, E.S., A. Dahle and K.A. Berteussen: 'Bias analysis of NORSAR and ISC reported $m_b$ magnitudes, In preparation.

## D. TRAVEL TIME ANOMALIES AND CRUSTAL STRUCTURE BENEATH NORSAR

Depth varying interfaces in the crust or mantle beneath the array have most commonly been used as the explanation of the kind of P-wave travel time anomalies observed at NORSAR (Berteussen 1974). Therefore an experiment has been made in order to find out how much of the observed anomalies that possibly can be explained by such interfaces.

The first step was to recompute the slowness calibrations and time delay corrections so they gave deviations relative to the wavefront predicted from the azimuth and distance to the NOAA epicenter solution. The part of these deviations which were from P-waves were then averaged in intervals of 10 degrees in azimuth. The first interface tested was a dipping plane. The equation for this may be written

$$Z = A + B \cdot X + C \cdot Y \qquad (1)$$

The coordinate system is centered in the array's center with X-axis towards east, Y-axis towards north and Z-axis upwards. The reference depth of all the interfaces tested was set to 33 km, that is, the interfaces may be thought of as the crust-mantle boundary. The velocity contrast was set to 6.6/8.2 (Kanestrøm 1971). The parameters B and C were then varied systematically until the sum of the squared differences between observed and predicted (because of the dipping plane) time deviations had its minimum. The values found for the parameters in eq. (1) and the percent reduction in mean square deviations are listed in row 1 Table D1. As seen, the plane is

TABLE D1

Table of coefficients for best plane, second degree interface and third degree interface. Per cent reduction in mean squared deviations is also listed for the three models.

| Model | A | $B\cdot10^3$ | $C\cdot10^3$ | $D\cdot10^3$ | $E\cdot10^3$ | $F\cdot10^3$ | $G\cdot10^6$ | $H\cdot10^6$ | $I\cdot10^6$ | $J\cdot10^6$ | % Gain |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plane | -33.0 | 90.4 | 22 | | | | | | | | 17.9 |
| 2nd degree | -33.4 | 99.3 | -7.9 | 0.47 | -2.0 | 0.3 | | | | | 21.4 |
| 3rd degree | -33.3 | 222.9 | 13.1 | 0.003 | -1.55 | 0.17 | 33. | -13.5 | -51.0 | -3.9 | 24.3 |

able to explain 17.9 per cent of the squared deviations. This plane has a dip of 6 degrees and updip direction 94 degrees clockwise from north. With another velocity contrast the dip of the interface would change while the updip direction would still be the same. The per cent reduction in mean square deviations would also be unchanged. This implies that nothing can be gained by moving the interface to another depth.

Since a dipping plane cannot satisfactorily explain the deviations, we will go further and try a second degree interface. The equation for this is:

$$Z = A + BX + CY + DX^2 + EXY + FY^2 \qquad (2)$$

When a curved interface can be described in this way, ray-tracing is especially simple and not very time-consuming on a computer. The procedure has been as before, namely, to vary all the coefficients in eq. (2) systematically. For each set of coefficients conventional ray-tracing has been applied in order to find the deviations this particular interface would give for our data points. The best interface is then the interface where the sum of the squared differences between predicted and observed deviations has been reduced to a minimum. The coefficients for this surface are listed in row 2, Table D1. As also can be seen from Table D1, this interface is able to explain only 21.4% of the squared deviations. The depth contours for this interface are plotted in Fig. D1.

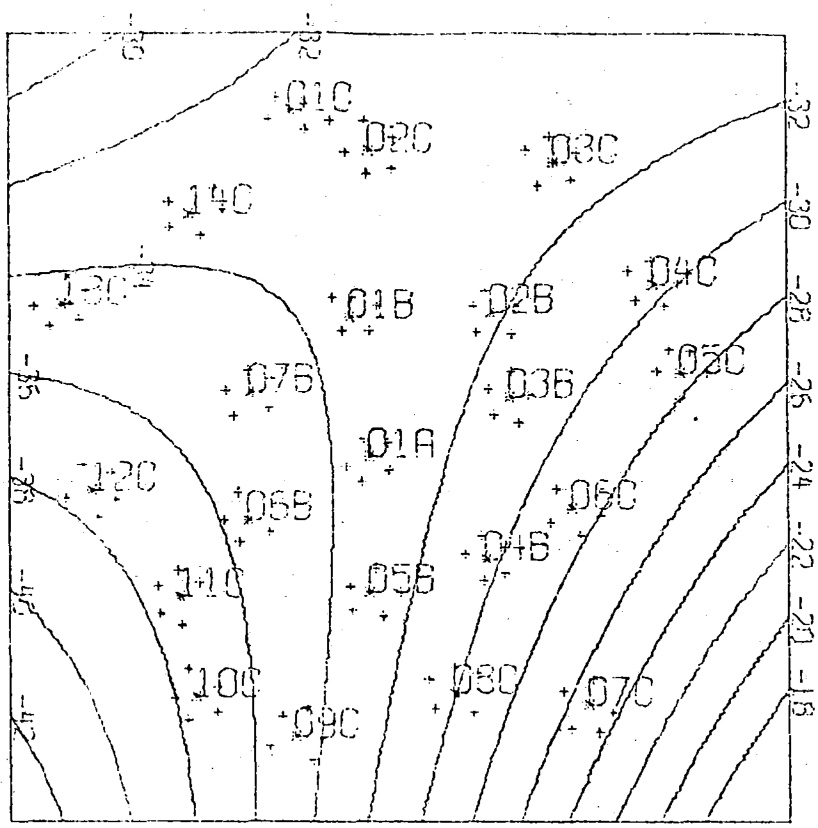



Fig. D1 Depth contours for best 2nd degree interface. $V_C$=6.6 km/sec, $V_M$=8.2 km/sec. The NORSAR array configuration is also included.

The next step was to use the same procedure over again, except that this time a polynomial of third order was used. The equation for this is:

$$Z = A + BX + CY + DX^2 + EXY + FY^2 + GX^3 + HX^2Y + IXY^2 + JY^3 \qquad (3)$$

The coefficients for this interface are listed in row 3, Table D1. This interface is able to explain 24.3% of the observed squared deviations. The contours for this are drawn in Fig. D2.

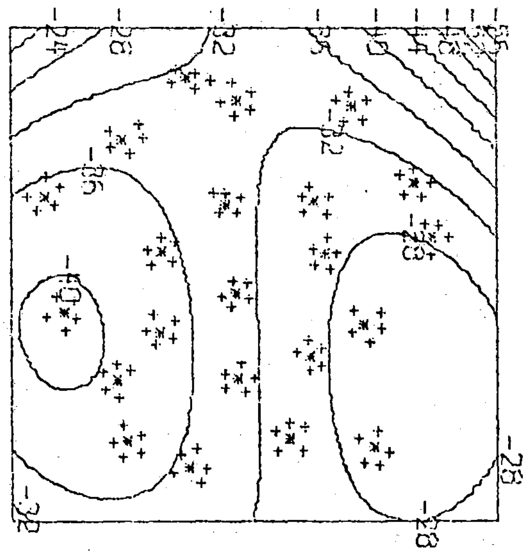


Fig. D2 Depth contours for best 3rd degree interface $V_C$=6.6 km/sec, $V_M$=8.2 km/sec.

As seen from Figs. D1 and D2, the interfaces found do exhibit such large elevation differences that their physical reality is questionable. To increase the order of the polynomial to higher degrees than 3 cannot be done because we then will end up with such a detailed map that simple ray theory may not be used. If the velocity in the crust above the interface is set to 6.2 km/sec, a second degree polynomial found in the same way as described in the above section will be able to explain 24.9% of the squared deviations. The conclusion is that it is not possible to construct a physically realistic interface which is able to explain more than say 25% of the sum of the squared deviations observed at NORSAR. It thus seems that in order to explain the bulk of the deviations observed, other models have to be introduced; that is, models where wave scattering and possibly multipathing take a more important part.

K.A. Berteussen

REFERENCES

Berteussen, K.A.: NORSAR location calibrations and time delay corrections, NORSAR Scientific Report No. 2-73/74, NTNF/NORSAR, Kjeller, Norway, 1974.

Kanestrøm, R., and K. Haugland: Crustal structure in southeastern Norway from seismic refraction measurements, Scientific Report No. 5, part 2, Seismological Observatory, University of Bergen, Norway, 1971.

## E. A CHERNOV MEDIUM ANALYSIS AT NORSAR

An analysis of the P-wave scattering taking place under NORSAR has been made. Totally 33 events and 54 instruments (subarrays 01A, 01B, 02B, 03B, 04B, 06B, 07B, 06C) have been used. The procedure applied is much the same as that of Aki (1973). That is, the phase and amplitude spectrum have been calculated within a time window of 5 seconds, starting at the arrival time given from the NORSAR plane wavefront estimate. Phase lag and amplitude were calculated at the frequencies 0.6, 0.8, 1.2, 1.6 and 2.0 Hz. The main conclusion from this analysis is that the P-wave scattering taking place under NORSAR is too strong for the Born (Chernov 1960) approximation to be fulfilled. This seems valid for all the frequencies tested. For further information see Capon and Berteussen (1973).

J. Capon (M.I.T. Lincoln Lab)
K.A. Berteussen

REFERENCES

Aki, K.: Scattering of P-waves under the Montana LASA, J. Geophy. Res., 78, 1334-1346, 1973.

Capon, J., and K.A. Berteussen: Semiannual Technical Summary Report to the Advanced Research Projects Agency, Mass. Inst. of Tech., Lincoln Lab., Cambridge, Mass., USA, December 1973.

Chernov, L.A.: Wave propagation in a random medium, Translated by R.A. Silverman, McGraw-Hill Book Company, New York, 1960.

F. SCATTERING OF P WAVES AT NORSAR

The standard linear deterministic model for travel time T (or logarithmic amplitude) at the i-th instrument of the array

$$T_i = T_o + \vec{U}\cdot\vec{R}_i + \varepsilon_i' \quad \text{(F1)}$$

where $T_o$ is a constant, $\vec{R}_i$ denotes position, $\vec{U}$ denotes systematic (trend) effect and $\varepsilon_i'$ denotes random error. is considered unsatisfactory to explain the complex variation in these parameters. To obtain an improved description we have tentatively put up a linear stochastic model with random error component (see Fig. F1)

$$T_i = T_o + \vec{U}\cdot\vec{R} + S_i + \varepsilon_i \quad \text{(F2)}$$

The important term in this equation is the stochastic signal $S_i$ which denotes the fluctuation in the parameter describing the wavefront according to eq. (F1).

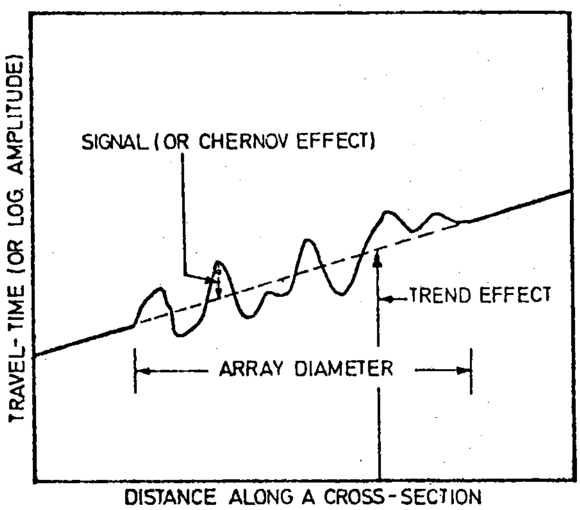



Fig. F1 Schematic decomposition of a stochastic model in a (systematic) trend effect and a correlated anomaly denoted signal.

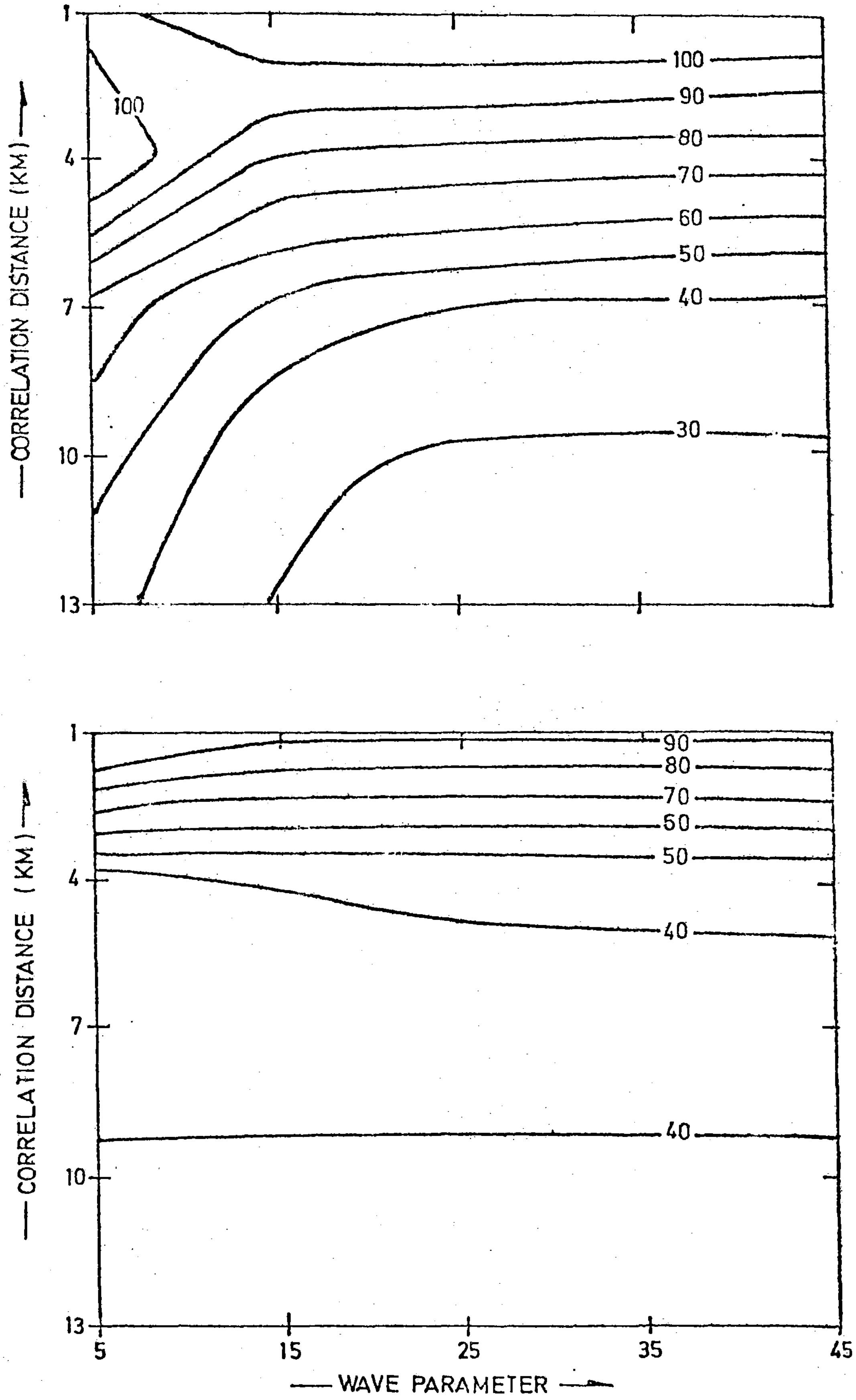



Fig. F2 Contour plot showing per cent variance of observed minus predicted travel times (lower) and logamplitudes (upper) using eq. (F2) relative to the same quantity using eq. (F1).

By stochastic we mean that $E\{S_i \cdot S_i^*\} = C$ where the C is a covariance matrix with off-diagonal elements different from zero. Physically this means that the fluctuations in travel time and logamplitude are spatially correlated.

As an appropriate theoretical back-up we have chosen the scattering theory for acoustic waves in a random medium by Chernov (1960), where the matrix C is related to properties (wave parameter, correlation distance) of the inhomogenous medium through which the waves have been travelling. Adopting Chernov's formulae for large scale inhomogeneities and implementing the related covariance matrix into eq. (F2), we are in a position to use prediction for correlated observations to show that (see Fig. F2) the residual variances are reduced by more than 50% relative to eq. (F1).

It should be stressed that trying to evaluate the covariance matrix C, we are concerned with difficulties like estimating the "true" deterministic trend $T_o + \vec{U} \cdot \vec{R}$, as well as separating the error residue $\varepsilon_i$ from the total anomaly $S_i + \varepsilon_i$

A consequence of the observations being correlated is that slowness estimates based on least squares estimation using eq. (F1) is less effective than using eq. (F2). In other words, when the array diameter is small and the spacing of sensors less than the correlation distance of the scattering medium, great care should be taken in interpreting velocity anomalies as structural discontinuities.

A. Dahle
K.A. Berteussen
E.S. Husebye
A. Christoffersson (Uppsala, Sweden)

RREFERENCES

Chernov, L.A.: Wave propagation in a random medium, (Translated by R.A. Silverman), McGraw-Hill Book Company, New York, 1960.

## G. SCATTERING SOURCES IN THE DEEP MANTLE AND P'P' AND PKP PRECURSOR WAVES

Precursors to PKP and PKKP phase are in general interpreted as ordinary core waves, and the corresponding physical explanation requires one or more layers in the fluid outer core. However, in the recent two years very careful analysis of array recorded precursor waves has resulted in slowness and azimuth values which are incompatible with the standard velocity models of the earth's core. For example, azimuth deviations up to ±50 deg are observed, while slowness values may vary from 1.0-4.5 sec/deg. Alternatively, the precursors may be interpreted in terms of scattering sources in the deep mantle, an explanation forwarded both by Cleary and Haddon (1972) and by Doornbos and Vlaar (1973). Moreover, Haddon (1973) has developed a wave-scattering theory which is an important tool in verifying the above scattering hypothesis.

Work is now in progress at NORSAR aimed at a detailed mapping of the 'scattering' properties of core precursor waves, both in time and space. The preliminary results obtained compare favorably to those based on theoretical calculations for scattering structures of the Chernov (1960) type in the deep mantle. To get a better check on the scattering models used, the theoretical calculations have to match the analysis results of precursor waves associated with different types of core phases.

R.A.W. Haddon (Sydney, Australia)
E.S. Husebye

## REFERENCES

Chernov, L.A.: Wave propagation in a random medium (Translated by R.A. Silverman), McGraw-Hill Book Company, New York, 1960.

Cleary, J.C., and R.A.W. Haddon: Seismic wave scattering near the core-mantle boundary: a new interpretation of precursors to PKP, Nature, 240, 549-551, 1972.

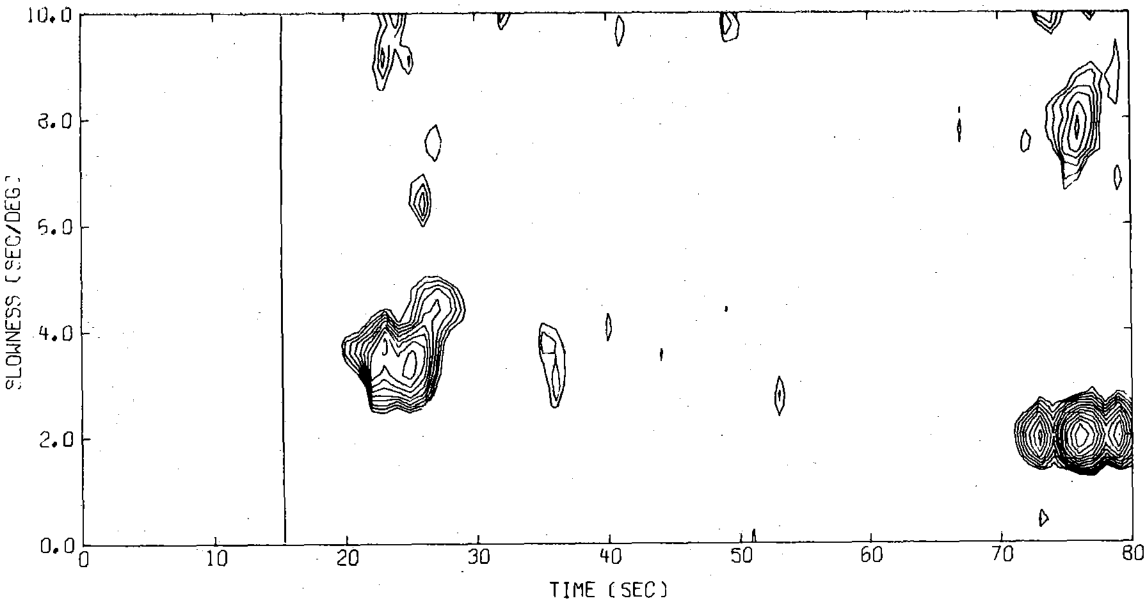
Doornbos, D. J., and N.J. Vlaar: Regions of seismic wave scattering in the earth's mantle and precursors to PKP, Nature Phys. Sci., 243, 126, 58, 1973.

Haddon, R.A.W.: Scattering of seismic body waves by small random inhomogeneities in the earth, Geophys. J.R. Astr. Soc., in press, 1974.

## H. SEISMIC WAVE SCATTERING NEAR CAUSTICS AND PKKP PRECURSORS

Precursors to PKP have recently been interpreted in terms of scattering structures in the deep mantle (Cleary and Haddon, 1972, Doornbos and Vlaar, 1973). It has been argued that the observability of the scattered waves is closely related to the presence of a caustic because of the focusing effect and because the scattered waves can enter the shadow zone at the concave side of the caustic, where they may manifest themselves as first arrivals. If the given interpretation is correct, then in suitable circumstances the scattering phenomenon should also be identifiable near other caustics.

In this note I report a test on the "scattering hypothesis" by means of Vespagram analyses in the shadow of the PKKP caustic, as the PKKP caustic agrees mostly with the one of PKP. The Vespa process has been discussed before (Davies et al, 1971, Doornbos and Husebye, 1972) and is known to be useful in a case like this, where one would expect small energy arrivals in the "noisy" coda. A typical Vespagram is shown in Fig. H1. It is processed to pick out the PKKP phases from an event at an epicentral distance of $131.6^{\circ}$. The PKKP caustic at the earth's surface is near $125^{\circ}$ and a shadow region for PKKP outer core phases extends from $145^{\circ}$ to larger distances, only PKKP which is reflected and/or refracted through the inner core will be expected here. In the Vespagram it is easy to identify as the inner core phase the peaks in the end of the time window at about 2.0 sec/deg, and it is clear then that there are one or more precursors, starting about 50 seconds before PKKP. As indicated in Fig. H1, the minimum arrival time for scattered waves is at about 15 seconds after Vespagram start time.



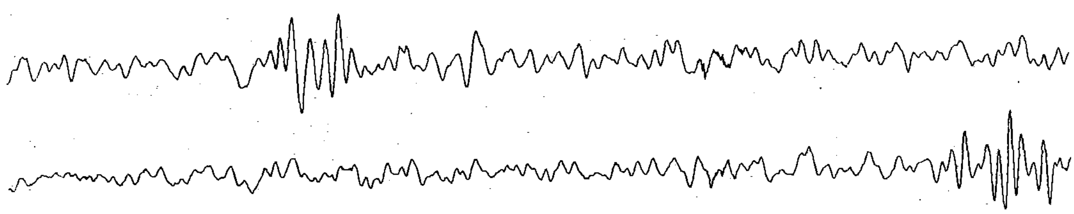



Fig. H1 A Vespagram processed to record PKKP phases from an event with or. time = Oct. 27, 1971, 17 hr, 58 min, 36.9 sec, magn. = 6.0, depth = 40 km. Epicentral distance from NORSAR = 131.6°. The Vespagram start time is at 18 hr, 26 min, 30 sec. Power is contoured from 1 to 12 dB below peak power, which is at 77 sec. The vertical line at 15 sec represents minimum arrival time for PKKP scattering from this event. The traces below the Vespagram represent the NORSAR beams directed towards the PKKP peak (lower trace) and its peak precursor (upper trace).

Fig. H2 summarizes the analysis of PKKP and its precursors from 8 events in the Solomon Islands region. Several of the events were fairly complicated, which will cause large arbitrariness in interpreting later arriving precursors. Therefore, only results for travel time and direction of approach of the first arriving precursor of each event have been given. $dT/d\Delta$ and azimuth of approach have been obtained by relocating the Vespagram maxima in frequency-wavenumber space, using the spectral analysis method from ref. 2. With these results the following comments can be made:

1) Scattering in the deep mantle at the source side ($dT/d\Delta$ probably > 4.2 sec/deg) and at the receiver side ($dT/d\Delta$ probably < 4.2 sec/deg) satisfactorily explains both slowness vectors and travel times, with a discrepancy of several seconds in only two cases. On the other hand, the hypothesis of layering in the outer core, which includes earlier interpretations of PKP precursors, will lead to a discrepancy not only in $dT/d\Delta$ (this would be below 3.3) but also in travel time (this would be 5-10 seconds late with respect to the data).

2) Ray tracing reveals that, with one exception, the data lead to scattering sources within a few hundred km from the core-mantle boundary. This is of course to be expected for first arrivals (see also Doornbos and Vlaar, 1973). Here, this tendency is reinforced by the transmission of PKKP through the core, which is significant only at near grazing incidence. The direction properties of scattering from a ray bundle near grazing incidence into the shadow will favour regions near the core-mantle boundary.

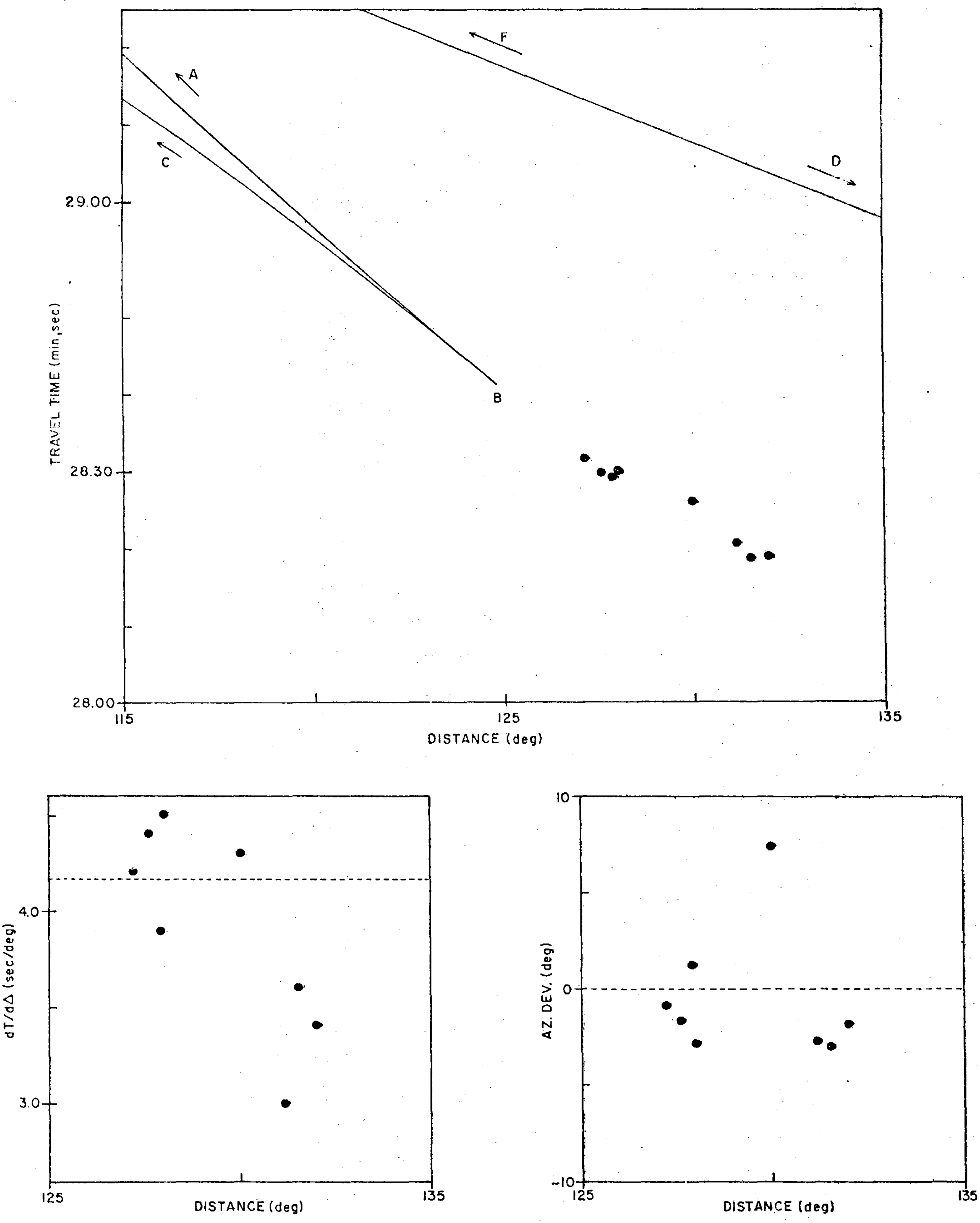



Fig. H2 Travel times and slowness vectors of first-arriving PKKP precursors. The distances adjusted to surface focus. In Fig. 2a observed travel time differences with PKKP have been referred to PKKP branches from a model of Buchbinder (1971). Fig. 2b gives dT/dΔ at cusp B for the reference model. Fig. 2c gives differences between the azimuth of approach and the back azimuth of the event. These differences are called azimuth deviations.

3) It is premature to infer finer structural detail from this limited data set. In particular, there is no such evidence for lateral variation as could be deduced from PKP precursor data at NORSAR (Doornbos and Vlaar, 1973), or as is suggested in another way by characteristics of direct P-waves (Davies and Sheppard, 1972). Of course, those variations are not necessarily manifest in the limited region, which could effectively be "seen" with the given configurations of sources and receiver.

D. Doornbos (Utrecht)

REFERENCES

Buchbinder, G.R.: A velocity structure of the earth's core, Bull. Seism. Soc. Am., 61, 429 (1971).

Cleary, J.R., and R.A.W. Haddon: Seismic wave scattering near the core-mantle boundary: a new interpretation of precursors to PKP, Nature, 240, 549 (1972).

Davies, D., E.J. Kelly and J.R. Filson: Vespa process for analysis of seismic signals, Nature Phys. Sci., 232, 8 (1971).

Davies, D., and R.M. Sheppard: Lateral heterogeneity in the earth's mantle, Nature, 239, 318 (1972).

Doornbos, D.J., and E.S. Husebye: Array analysis of PKP phases and their precursors, Phys. Earth Planet. Int., 5, 387 (1972).

Doornbos, D.J., and N.J. Vlaar: Regions of seismic wave scattering in the earth's mantle and precursors to PKP, Nature Phys. Sci., 243, 58 (1973).

# I. CODA CONTENTS AND MULTIPATHING OF RAYLEIGH WAVES AT NORSAR

One of the most important problems in seismic discrimination today is how to improve the detectability of surface waves. As a contribution here a study has been completed (Bungum and Capon, 1974) in which the Rayleigh wave codas from 15 events recorded at NORSAR have been analyzed in detail with respect to power distribution in time, velocity and direction, for period of 20 and 40 sec. This has been done using the high-resolution (HR) frequency-wavenumber analysis method (Capon 1969).

A fairly extensive simulation experiment was first performed in order to learn more about the capabilities and the limitations of the HR-method when applied to this particular problem. One fundamental limiting factor is that the diameter of the array is slightly less than the wavelengths under analysis (at 40 sec period) and another problem is that we are analyzing transient signals and only 200 sec of data at a time. When the problem of detecting one signal in the presence of another is considered, the simulations (using both artificial and real data) showed that one of the most important parameters is the amount of overlap in time between the two waves. This is clearly demonstrated in Fig. I1, where different arrival times are used on otherwise identical signals. It should be noted that when the two wavetrains overlap completely, no resolution is possible regardless of method employed.

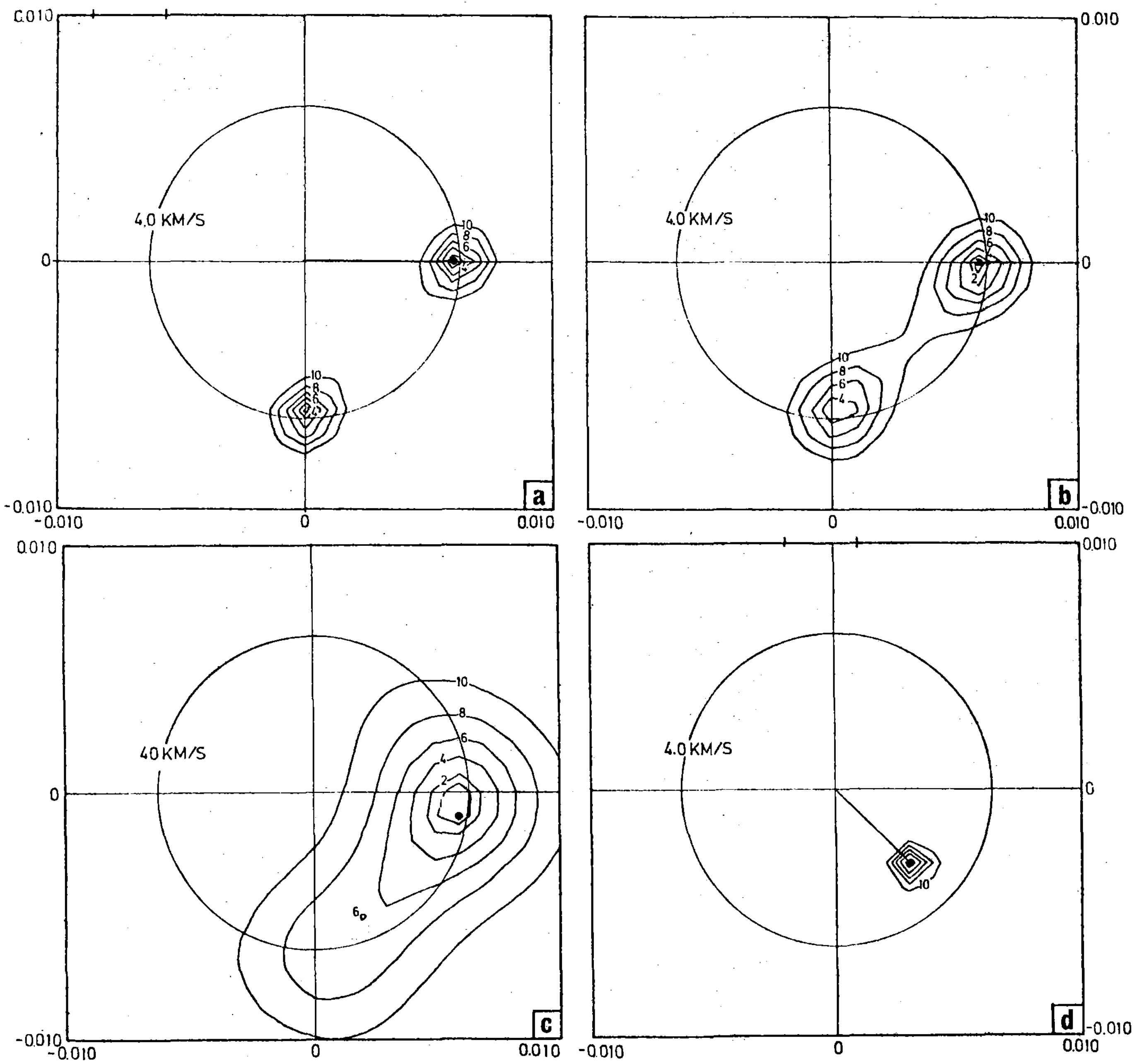



Fig. I1 Wavenumber spectra for simulation data using the HR-method on the sum of two sine waves $90^{\circ}$ apart, both with velocity 4.0 km/sec. The four cases represent (a) no overlap in time between two waves, (b) 25% overlap, (c) 50% overlap, and (d) full overlap. Each spectrum is estimated from two 100 sec blocks of data.

Another problem in the calculation of wavenumber spectra is that errors are introduced due to the grid quantization in wavenumber space. The distribution of azimuth errors introduced in this way is given in Fig. I2, where it can be seen that the errors are in the range ±5 degrees. Similar quantization errors are introduced in the velocity measurements, and it has been found, based on certain assumptions about expected phase velocities, that this leads to an accepted velocity range of 3.5-4.2 km/sec for 40 sec period waves, and 3.4-4.0 for 20 sec.

For all the 15 events, which have a relatively uniform geographical distribution, the power vs. time has been calculated. The average of this is presented in Fig. I3, which shows that the power drops off faster at 40 sec than at 20 sec. For this reason, the amount of interference should be less at 40 sec. However, this is compensated for by the fact that the resolving power of the array is better at 20 sec.

Besides the estimate of power, the analysis has also given phase velocity and azimuth for successive non-overlapping 200 sec blocks of data. This gives a picture of the multipath propagation, and it has lead to proposals for ray paths for some of the events. An example is given in Fig. I4, which shows that severe multipathing is taking place, especially for 20 sec period. This event is relatively typical for what we see, at 40 sec there is usually a well-defined main group arriving along or close to the great circle path, while at 20 sec the energy is typically dispersed over an angle of 40-60 degrees, with no clear onset.

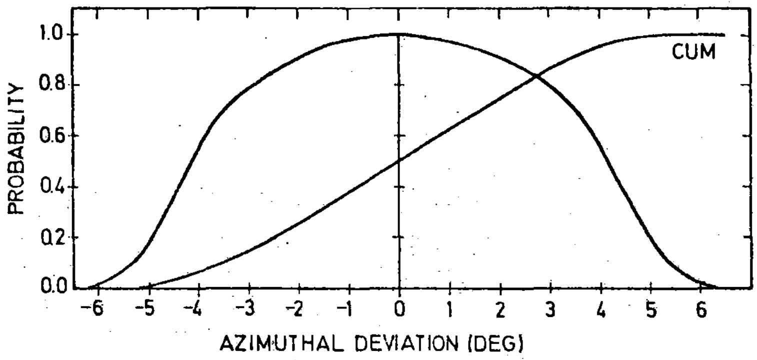



Fig. I2 Normalized incremental and cumulative distributions of azimuthal quantization errors using a wavenumber grid with increments of 0.001 c/km to measure a wave with a velocity distribution centering on 3.85 km/sec and a period of 40 sec.

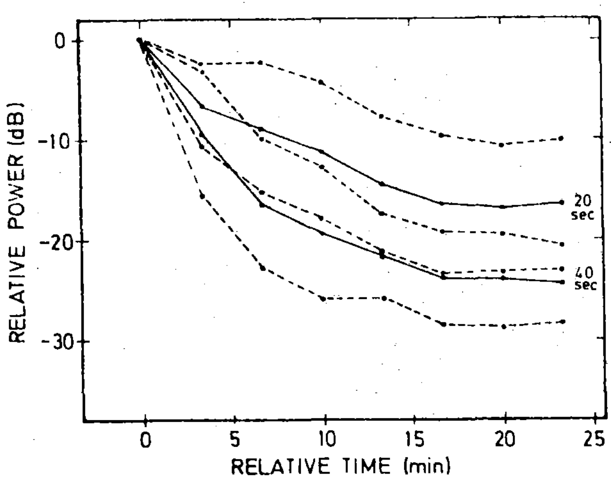



Fig. I3 The average of the coda power distributions for 15 events at periods of 40 and 20 sec. The standard deviations are indicated by dotted lines.

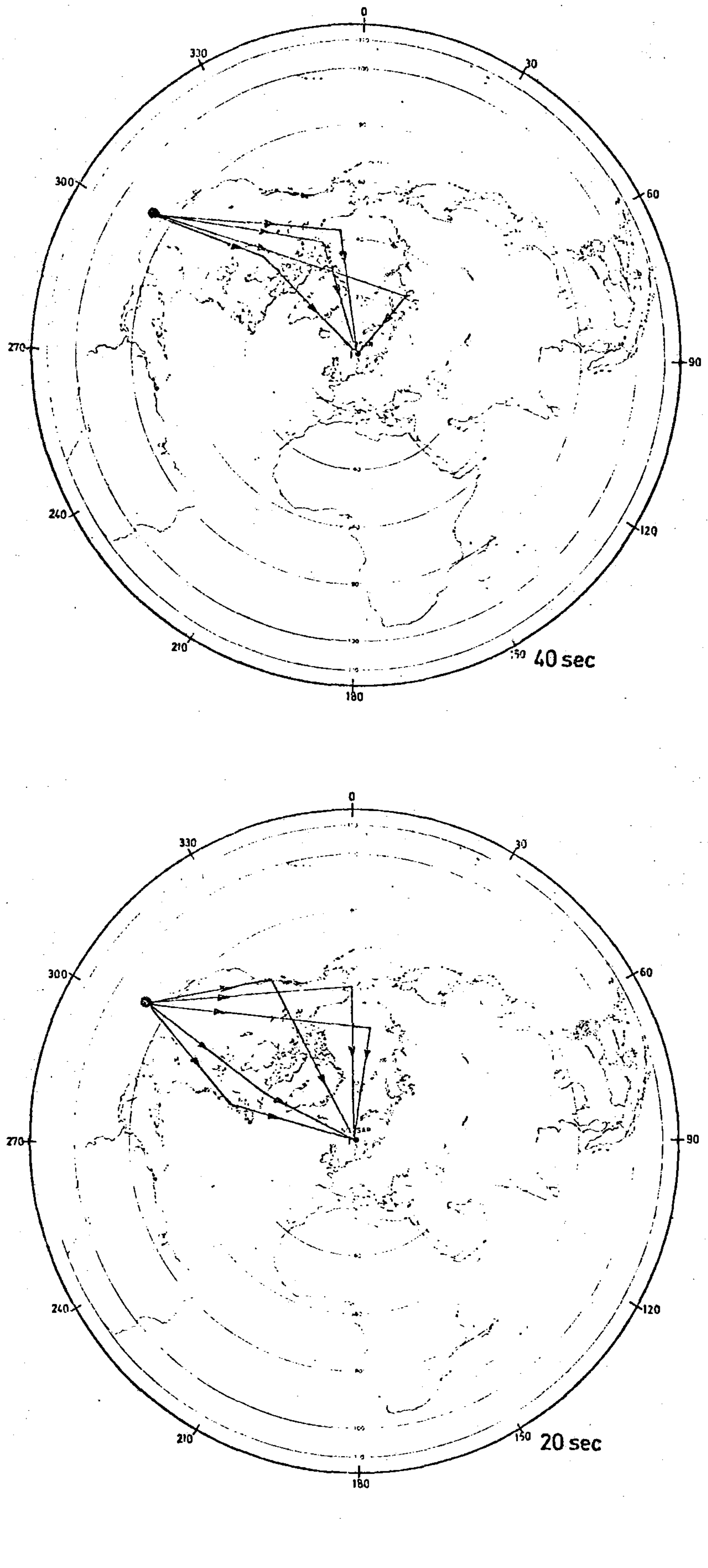



Fig. I4 Ray path solution for an event from California for period of 40 and 20 sec.

These observations do have some implications which should be stressed specifically. First of all, the multipathing complicates the detection problem a great deal. This is because the distribution of energy both in time and frequency-wavenumber space becomes very complex and therefore difficult to recognize and identify, and also because it greatly adds to the confusion when two events are appearing simultaneously. Next, the effect of this multipathing on Rayleigh wave magnitude determinations can also be serious, pointing towards the preference of an algorithm using information from a wider band both in time and frequency. Besides this, the multipathing also strongly affects the precision with which one can measure group velocities, which traditionally are based on the assumption of wave propagation along great circle paths.

H. Bungum
J. Capon (M.I.T. Lincoln Lab)

REFERENCES

Bungum, H., and J. Capon: Analysis of coda and multipath propagation of Rayleigh waves at NORSAR, NORSAR Scientific Report 3-73/74, NTNF/NORSAR, Kjeller, Norway, In press, 1974.

Capon, J.: High-resolution frequency-wavenumber spectrum analysis, Proc IEEE, Vol 57, 1408-1418, 1969.

J. SEISMICITY OF THE GREENLAND AND NORWEGIAN SEAS

Extensive efforts have been made in the recent years to investigate the geological and geophysical features of the Greenland and Norwegian Seas, and a relatively consistent picture of past and present tectonic movements has been obtained. Since earthquake occurrence is closely associated with such features, a study of seismicity pattern may provide additional evidence of tectonics besides being a valuable tool for outlining new areas which should be subject to further investigation.

At NORSAR a study of the seismicity of this region is in progress, predominantly based upon events reported by Sykes from the period 1955-60 and by NOAA (National Oceanic and Atmospheric Administration) from 1961-72. As precision in the epicenter estimates represents a limitation in all seismicity studies, an analysis was made to get an idea of the errors involved. The conclusion was that more than 10 reporting stations give a precision of about 20-30 km in most cases.

Expectedly, little new evidence was obtained at the mid-oceanic ridges and major fracture zones, as these areas have been thoroughly investigated earlier, also with respect to seismicity (Sykes 1965). However, a series of quite interesting features were discovered outside these main belts, especially at the Norwegian-Barents shelf and in the Lofoten basin. The seismicity pattern is disucssed in the light of earlier works and attempts are made to relate seismic activity to known or postulated movements. Furthermore, a search in literature has resulted in a list of 14 focal plane solutions, most of which show a reasonable agreement with expected tectonic features. A few events have very interesting solutions, emphasizing the need for additional focal mechanism studies in the Norwegian-Greenland Sea.

E.S. Husebye
H. Gjøystdal
H. Bungum

REFERENCES

Sykes, L.R.: The seismicity of the Arctic, Bull. Seis. Soc. Am., Vol 55, no 2, 519-536, April (1965).

## K. DETECTION PROCESSOR OPERATION

The mode of operation of the Detection Processor (DP) has for this period essentially been the same as for last period, i.e., minimal system down time. Average recording time has been, according to Table K1, 98.3% as compared to 98.8% for the last reporting period. No significant changes have been made to the DP software in the reporting period.

### Data Recording and DP Down Time

Fig. K1 shows the DP down time each day from 1 July to 31 December in 1973. The total monthly recording time is given in Tables K1, K2 and K3, which also give statistics on general computer usage. As can be seen in Fig. K1, the causes of the longest/most frequent down time intervals were respectively,

- a repeatedly occurring power drop on the A-computer
- a console typewriter hardware problem
- a case of all communication lines down
- a hardware failure in the SPS
- a cable break.

The power drops on 2 and 3 July caused seven down periods, giving a total down time of close to five hours for these two days.

The console typewriter error caused the DP to remain down in the time interval 1703 to 1842 on 30 August.

On 4 September, all lines were down from 0730 to 1135, again causing DP to be down in this time interval.

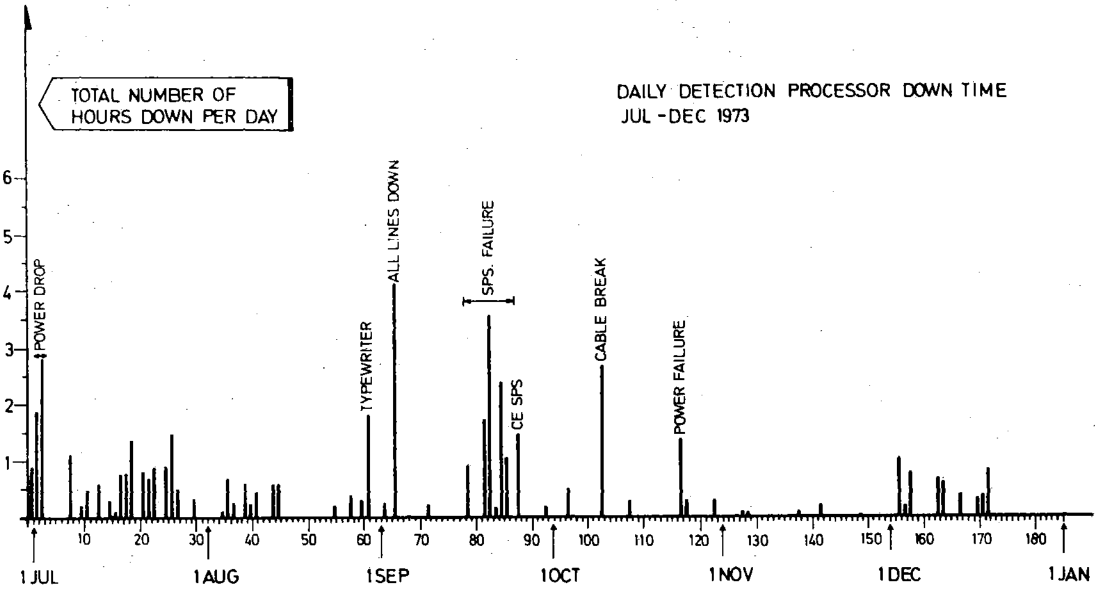



Fig. K1 Daily Detection Processor down time Jul-Dec 1973.

TABLE K1

DP and EP Computer Usage, 1 July - 31 December 1973.

| Month | DP Uptime (hrs) | DP UP (%) | EP Uptime (hrs) | EP Up (%) | No. of DP Error Stops | DP MTBF (Days) |
|---|---|---|---|---|---|---|
| Jul | 734 | 98.7 | 346 | 46.5 | 32 | 1 |
| Aug | 737 | 99.1 | 321 | 43.1 | 20 | 1.5 |
| Sep | 680 | 94.4 | 298 | 41.4 | 33 | 0.9 |
| Oct | 735 | 98.8 | 354 | 47.6 | 8 | 3.8 |
| Nov | 718 | 99.7 | 262 | 36.4 | 5 | 6.0 |
| Dec | 737 | 99.1 | 234 | 31.5 | 15 | 2.0 |
| Total | 4341 | 98.3 | 1815 | 41.1 | 113 | 1.6 |

TABLE K2

A-Computer Usage (hrs), 1 July - 31 December 1973.

| Month | DP | EP | Job Shop | Data Ret. Copy | AM | DP Test | C.E. Maint. | Power Down | Data Lines Down | Machine Fail. | DP Down for TIP | SPS Failure | Plot in Fl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul | 523 | 82 | 151 | | 13 | 0.4 | 1 | 1 | | 26 | 2 | | 132 |
| Aug | 732 | | 2 | | | 0.5 | 3 | | | 3 | 1 | | 145 |
| Sep | 680 | | | | | 0.3 | 3 | 1 | 25 | 2 | 1 | 6 | 140 |
| Oct | 735 | | | | | | 0.1 | 3 | 2 | 2 | | | 147 |
| Nov | 654 | 39 | 49 | | | 5 | 3 | | | 1 | | | 125 |
| Dec | 737 | | | | | | 0.2 | | | 4 | | | |
| Total | 4061 | 121 | 202 | | 13 | 6 | 10 | 5 | 27 | 38 | 4 | 6 | 784 |

TABLE K3

B-Computer Usage (hrs), 1 July - 31 December 1973.

| Month | DP | EP | Job Shop | Data Ret. Copy | AM | DP Test | C.E. Maint. | Power Down | Mach-ine Fail. | Hands On | Plot In Fl |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul | 211 | 264 | 386 | 34 | 18 | 3 | 3 | 1 | 4 | | 120 |
| Aug | 5 | 321 | 488 | 18 | 444 | 15 | 4 | | 4 | | 110 |
| Sep | | 298 | 515 | 72 | 78 | 9 | 3 | 1 | | | 108 |
| Oct | | 354 | 610 | 45 | 43 | 41 | 2 | 3 | | 3 | 112 |
| Nov | 64 | 223 | 490 | 78 | 29 | 52 | 6 | | 8 | 2 | 116 |
| Dec | | 234 | 506 | 101 | 46 | 0.4 | 2 | | | 1 | 164 |
| Total | 280 | 1694 | 2995 | 348 | 258 | 120 | 20 | 5 | 16 | 6 | 730 |

A faulty frame in the Special Processing System (SPS) caused DP to go down 28 times between 0600 on 17 September and 0923 on 24 September. Most of the down intervals were of the order of 10 minutes. Major down periods were on 17 September (1 hour and 54 minutes), 20 September (27 minutes), 21 September (2 hours and 47 minutes) and 23 September (59 minutes). Also a customer engineering session on the SPS on 25 September caused DP to be down 1 hour and 2 minutes.

A cable breakage on 11 October gave a down period from 1701 to 1942.

A power failure on 25 October gave another down period from 1740 to 1906.

The 113 DP error stops in this period are related to the following causes:

| | | |
|---|---|---|
| Tape drive problems | : | 11 |
| Power breaks and related stops | : | 12 |
| SPS problems | : | 33 |
| Other hardware problems | : | 23 |
| Operator errors | : | 7 |
| CE maintenance | : | 13 |
| Software problems | : | 9 |
| TOD (Time of Day) adjustment | : | 1 |
| Unknown | : | 4 |

Under "software problems" are also counted restarts with program modifications. The average mean time between failures in this period was 1.6 days. Apart from these error stops, no major operational problems have occurred while running DP.

## DP Algorithms and Parameters

No major changes have been introduced to the DP algorithms in the reporting period. A small modification in the punched card processor was introduced 4 September to correct a punching error occurring infrequently on the data cards for the tape library program.

D. Rieber-Mohn
H. Bungum

## L. EVENT PROCESSOR (EP) OPERATION

### General Considerations

The data analysis part of the EP operation in this reporting period has followed a pattern which is now well-established. The analysts are quite experienced and have acquired a good knowledge about the observations from the different seismic regions of the world. A completely automatic and quite reliable seismic bulletin is now being sent out to seismological institutions in Scandinavia on a daily basis (NORSAR System Operations Report, 1 Jan - 30 Jun 1973), in order to assist them in their daily analysis work. However, we strongly believe that use of experienced analysts will always improve considerably the quality of the seismic bulletin. In case of NORSAR, most of the event solutions are accepted as they appear from the automatic EP, but quite a few solutions are also changed manually, later phases are matched, etc. The final NORSAR bulletin is prepared every week, and now sent out to 56 institutions.

The operation of the EP programs in this period has been hampered by some serious problems, mainly caused by disk/ tape I/O operations. This again reflects the fact that EP is not as robust as could be desired. To improve tape handling and the disk I/O, modifications either already have been implemented or will be shortly.

## Computer Utilization

During this reporting period, EP was up 41.1% of the time, according to Table K1. This is a small increase from the last reporting period, where the same number was 40.3%. Two factors may have contributed to this: the increased noise level at this time of the year causes an increasing amount of false detections to be processed by EP. Also, a certain amount of re-processing has taken place within this period.

## EP Operational Problems

The TAL (Trans-Atlantic Link) file is still causing problems, being very vulnerable to improper operation of the EP system. A hangup of the file, causing no EP data to be transferred over TAL, went unnoticed from 08/23/73 to 09/06/73, before an off-line reset program was run to start up the data transfer through the file again. The hangup was caused by an improper operator action, causing EP to loop in Job Step 3 in the "Publish" mode.

Another weak point in the Event Processor design is the assignment of a partition in the Detection Bulletin File Generation Package, where hangups occur when, for some reason, an improper date has been inserted in the header(s). The logic, as it is now, is not capable of dealing with such a situation, and looping is taking place. However, by the end of the year, off-line programs for resetting pointers/entries in the TAL file, the Detection file and the Detection/Bulletin file were developed, thus making it easier to deal with such situations. Also the possibility of improving the logic in EP dealing with these files will be investigated.

A lacking card in the object version of Monitor Common, and an End-of-File mark in the middle of Event Data Set 2 also had disturbing effects on the regular EP-processing, until errors were discovered and corrected. The general hardware problem of badly performing tape drives has also, to a certain extent, influenced the EP performance.

## EP Parameters and Algorithms

No major changes have been implemented in the Event Processor system in this period.

On 30 July a change in the Job Step 3 coding, that prevented the Parameter Report from being printed unless a "fresh start" had been performed, was implemented.

The tape management routine was changed on 28 November, by adding code, making it print out the sense bytes on the 1052 Console typewriter when it declares a unit "down".

## EP Performance Statistics

A summary of the analyst decisions for each of the detections processed by EP is given in Table L1. The number of noise detections (25.6%) is usually higher during the second half of the year as compared to the first half, this being caused by the many meteorological storms off the west coast of Norway throughout the fall. These variations always make it necessary to change the SNR-threshold on a seasonal basis, so that the number of noise detections is always kept at a reasonable

TABLE L1

Analyst decisions for detections processed by EP during the time period July-December 1973.

| Analyst Classification | Number of Processings | Percentage |
|---|---|---|
| Accepted as events | 3478 | 42.5 |
| Rejected as being | | |
| - Poor SNR or noise | 2090 | 25.6 |
| - Local Events | 1085 | 13.3 |
| - Double processings | 654 | 8.0 |
| - Communications errors | 869 | 10.6 |
| Sum processed | 8176 | 100.0 |

level. The numbers of local events processed is still quite high (13.3%), and so is the number of errors on the communication lines (spikes) causing detections. However, most of these detections are identified as such already in DP, and changes are now initiated so that they will not be processed unless there is reasonable doubt as to their origin. The statistics of the reported events is given with somewhat more detail in Table L2 and also shown in Fig. L1. The total number of events is decreasing throughout the fall due to the above-mentioned noise conditions, and the average number per day is 17 as compared to 20 for the first half of 1973. 80% of the reported events are teleseismic and 20% core phase events, which is the typical relationship for NORSAR.

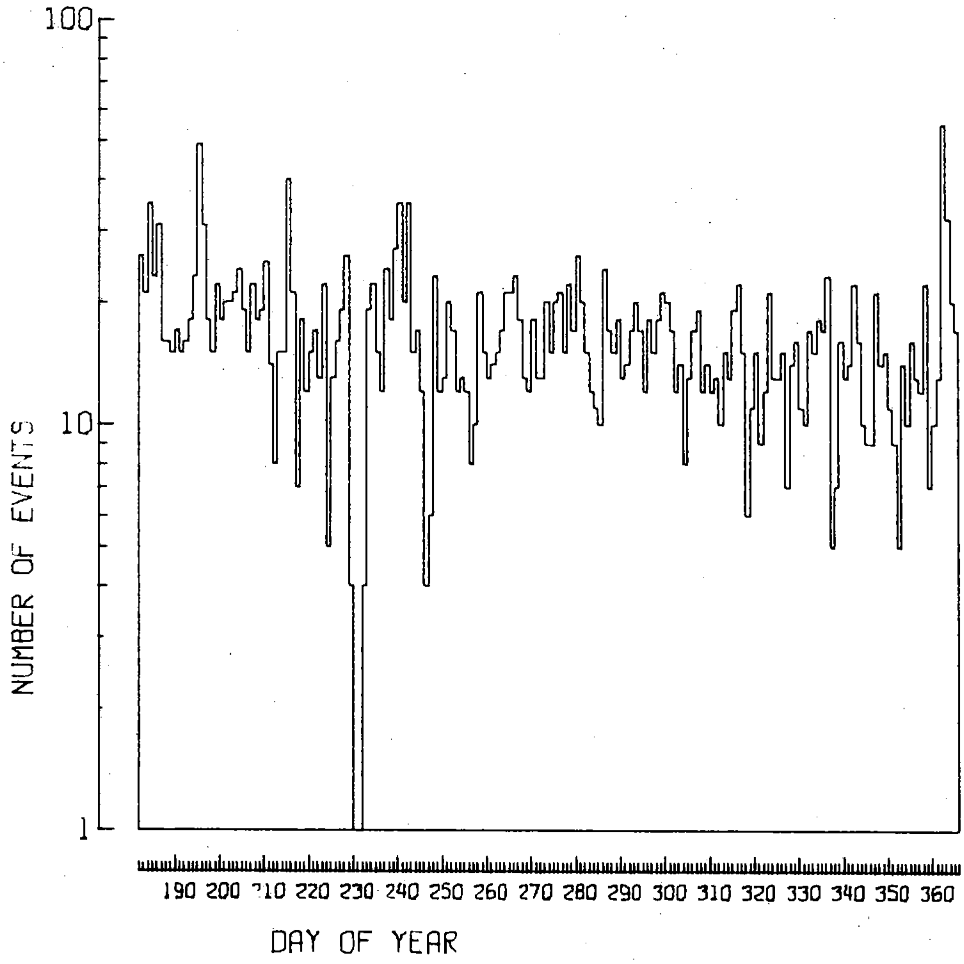



Fig. L1 Number of reported events as a function of day of year for Jul-Dec 1973.

TABLE L2

Number of teleseismic and core phase events reported by NORSAR during the time period July-December 1973.

| Month | Teleseismic | Core | Sum |
|---|---|---|---|
| July | 538 | 112 | 650 |
| August | 407 | 117 | 524 |
| September | 366 | 80 | 446 |
| October | 422 | 92 | 514 |
| November | 349 | 69 | 418 |
| December | 324 | 153 | 477 |
| Sum | 2406 | 623 | 3029 |

H. Bungum

D. Rieber-Mohn

P. Engebretsen

## M. PROGRAMMING ACTIVITY

The activity of the programming group in this period falls in the following, partially overlapping, categories:

- development of new programs
- maintenance of program systems
- support and routine processing.

The maintenance of program systems will be described separately in their respective chapters (K and L). Also, some time has been used to study documentation related to ARPANET (see Chapter N). Some programming support and consultative help has been given to visiting scientists.

### Development of New Programs

The following programs have been designed and coded in this period:

- A program that lists the Event Processor SYSLST-tape on the printer, and at the same time punches Edited Bulletin Reports on cards, if any are found on the tape. By using this program computing time is saved, which otherwise would be used to hunt for the correct Edited Bulletin on the Event Tape.

- A complete inventory program for NTNF/NORSAR equipment.
- A subroutine that allows the programmer to give the end coordinates, instead of the starting point coordinates of a number to be plotted.
- A program that selects specified records from the Detection Log Tapes and copies the records onto output tapes in one or more runs.

- A program that copies long period records in specified data intervals from Low Rate tapes onto an output tape.
- A one-event processor scheduler, that uses the Event Processor packages and facilities to compute a solution (Summary Report and Plot output) for one single event, based on input parameters given over the 1052 Console typewriter. In this way a facility for getting an EP solution for a specified event is available, without having to wait for the delayed on-line EP solution.
- A program giving a statistical summary of the data output from the Array Monitoring process.

Support and Routine Processing

The following routine and support jobs have been performed throughout the period, contributing significantly to the work load:

- Maintenance of the tape library directory, using the Tape Library program,
- Job shop runs of developed analysis programs for scientists and foreign visitors,
- Running of discrimination test programs and compilation of explosion data,
- Administration and control of the Data Retention procedure,
- Administration of a large amount of DP off-line runs, for an investigation on signal detectability and false alarm rate, and
- Investigation and record keeping of DP on-line unscheduled stops.

D. Rieber-Mohn
R. Rud
S. Skribeland

N. THE NORSAR ARPANET CONNECTION

A Terminal Interface Processor (TIP) was installed at NORSAR in June, giving access to the ARPANET via the TIP at Seismic Data Analysis Center (SDAC), Alexandria, Virginia. At the beginning of the period, various problems were being worked on, ranging from policy questions involving NTA (Norwegian Telecommunications Administration) and carrier companies to hardware/software problems with TIP and communications circuits. After an initial test period, TIP problems were successively solved in September. However, the Trans-Atlantic Link was not performing satisfactorily. The problem seemed to be connected with the higher speed; the "voice grade" line previously used for 2.4 kbit/s transmission should now handle 9.6 kbit/s traffic. After repeated upgradings, reroutings and tests, the line at the end of the year operates fairly satisfactorily. A preliminary investigation, however, shows a (slight) degradation of seismic data received from SDAC, compared to the pre-TIP conditions.

The TIP at University of London Institute of Computer Science was connected to the NORSAR TIP in the middle of October, via 4.6 kbit/s circuit. Thus the final arrangement gives ULICS and NORSAR a shared 7.2 kbit/s access to the network, as NORSAR seismic data transmission occupies 2.4 kbit/s out of the 9.6 kbit/s, via multiplexer.

At the end of the report period, three terminals were connected to the NORSAR TIP: one at NORSAR and one each at the neighboring institutions Blindern-Kjeller Computer Facility and the Norwegian Defence Research Establishment.

Some experience in the use of foreign ARPANET hosts has been gained by members of the NORSAR programming staff. Knowledge of and familiarity with login procedures, file handling methods and a variety of service programs (FORTRAN, TECO, NLS), as well as the operating system commands (TENEX), has been obtained, on especially two Host computers: The Stanford Research Institute, Augmentation Research Center PDP-10, and the University of Southern California Information Science Institute PDP-10.

A proposal has been worked out, listing how NORSAR wants to use its ARPANET TIP connection for remote computing and data exchange. Realization of the proposal requires interfaces for the 360/40 machines, for user Host attachment, as well as software development for the 360s. More specific plans have been worked out for one aspect of the data exchange, namely, transmission of the NORSAR bulletin to USGS, via an ARPANET Host, and implementation of the procedure is well under way.

Also, studies of the Network protocols have been initiated, in order to prepare for implementation of the software.

P. Tveitane
D. Rieber-Mohn

O. NORSAR DATA PROCESSING CENTER (NDPC) OPERATION

Data Center

The Data Processing Center at Kjeller consists of a rented permanent building containing computer room, adjacent rooms for air conditioning, card punching, line termination, storage and six offices, and a semi-permanent prefabricated office building with 17 offices and auxiliary rooms, part of which is U.S. Government property, part of it hired.

The Operations group consists of Operations Manager, OM Assistent, Operator Supervisor and 10 operators. During the report period two operators left the project, whereas 4 new operators were hired, thus filling vacancies existing at the beginning of the period. Computer operation is based on shift work, 2 operators per shift, 5-week cycle.

Maintenance for IBM-delivered equipment, contracted with IBM Norway, continued on "minimum service" basis, i.e., nine hours a day, Monday through Friday, for standard equipment, plus "time and material" for non-standard equipment.

A somewhat more frequent failure rate of peripheral equipment (tape and disk drives, card readers) was experienced. This is ascribed to aging of equipment. A more intensive monitoring of equipment performance is initiated.

Communications

The summer of 1973 was even more critical for the communications system than previous summers. In addition

Table 01

Communications, degraded/outages.

| Sub-arrays | JUL | | AUG | | SEP | | OCT | | NOV | | DEC | | Total Hours Degraded/Down | | Per cent Degraded/Down | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | >20 | >200 | >20 | >200 | >20 | >200 | >20 | >200 | >20 | >200 | >20 | >200 | >20 | >200 | >20 | >200 |
| 01A | 6.0 | 9.5 | 9.0 | 10.0 | 18.5 | 70.5 | 17.5 | 122.0 | 7.0 | 11.0 | 10.5 | 6.0 | 68.5 | 229.0 | 1.6 | 5.2 |
| 01B | 6.0 | 9.5 | 25.0 | 85.5 | 82.5 | 24.0 | 22.5 | 22.0 | 119.5 | 107.0 | 10.0 | 3.0 | 265.5 | 251.0 | 6.0 | 5.7 |
| 02B | 5.0 | 9.5 | 9.0 | 85.5 | 19.5 | 24.0 | 13.5 | 76.5 | 6.5 | 10.5 | 11.0 | 5.5 | 64.5 | 211.5 | 1.5 | 4.8 |
| 03B | 5.0 | 9.5 | 9.0 | 85.5 | 19.0 | 23.5 | 11.5 | 38.5 | 7.0 | 10.5 | 11.5 | 3.0 | 69.0 | 170.5 | 1.6 | 3.9 |
| 04B | 5.0 | 9.5 | 6.0 | 105.0 | 19.0 | 23.5 | 12.5 | 40.0 | 6.0 | 28.0 | 8.0 | 3.0 | 56.5 | 209.0 | 1.3 | 4.7 |
| 05B | 2.0 | 25.0 | 35.0 | 92.0 | 8.5 | 33.0 | 4.0 | 110.5 | 2.5 | 1.5 | 7.0 | 2.0 | 59.0 | 264.0 | 1.3 | 6.0 |
| 06B | 2.0 | 25.0 | 45.0 | 199.0 | 48.7 | 88.0 | 17.0 | 41.0 | 18.5 | 3.0 | 8.5 | 3.0 | 139.5 | 359.0 | 3.2 | 8.0 |
| 07B | 2.0 | 25.0 | 2.0 | 194.5 | 6.0 | 24.5 | 3.5 | 26.0 | 2.0 | 2.0 | 8.0 | 2.5 | 23.5 | 284.5 | 0.5 | 5.5 |
| 01C | 1.5 | 26.0 | 2.0 | 8.0 | 6.0 | 58.0 | 3.5 | 41.0 | 2.0 | 3.5 | 6.0 | 1.0 | 21.0 | 137.5 | 0.5 | 3.0 |
| 02C | 7.5 | 35.0 | 6.5 | 230.5 | 17.5 | 57.0 | 13.5 | 44.0 | 5.5 | 5.0 | 9.0 | 5.0 | 59.5 | 376.5 | 1.3 | 8.5 |
| 03C | 8.0 | 33.0 | 10.5 | 90.5 | 17.5 | 20.0 | 15.5 | 24.5 | 7.5 | 5.0 | 8.0 | 5.0 | 100.0 | 178.0 | 2.3 | 4.0 |
| 04C | 8.0 | 34.0 | 57.5 | 164.5 | 16.0 | 25.5 | 20.5 | 25.5 | 6.0 | 6.5 | 8.0 | 5.0 | 116.0 | 261.0 | 2.6 | 5.9 |
| 05C | 8.0 | 34.0 | 10.5 | 35.5 | 17.5 | 72.0 | 15.0 | 33.0 | 6.0 | 6.5 | 8.0 | 5.0 | 65.0 | 186.0 | 1.5 | 4.0 |
| 06C | 8.0 | 33.5 | 10.0 | 86.5 | 13.0 | 24.5 | 13.5 | 55.0 | 6.5 | 5.5 | 8.0 | 5.0 | 59.0 | 210.0 | 1.3 | 4.8 |
| 07C | --- | --- | --- | 18.0 | 168.5 | 0.5 | 0.5 | 15.5 | --- | --- | 4.0 | --- | 173.0 | 34.0 | 3.9 | 0.8 |
| 08C | --- | --- | 1.0 | 439.0 | 0.5 | 145.0 | 0.5 | 15.5 | --- | --- | 3.5 | --- | 5.5 | 600.0 | 0.1 | 13.6 |
| 09C | 0.5 | 414.5 | 2.0 | 85.5 | 5.0 | 11.0 | 4.5 | 36.0 | 3.5 | 0.5 | 6.0 | 1.0 | 21.5 | 548.5 | 0.5 | 12.4 |
| 10C | 99.5 | 563.0 | 3.0 | 244.0 | 6.0 | 11.5 | 4.0 | 35.0 | 4.0 | 2.0 | 7.0 | 1.0 | 123.5 | 856.5 | 2.8 | 19.4 |
| 11C | 1.5 | 21.0 | 7.5 | 85.0 | 7.5 | 11.5 | 4.5 | 22.5 | 4.0 | 2.0 | 5.5 | 1.0 | 30.5 | 143.0 | 0.7 | 3.2 |
| 12C | 26.0 | 622.0 | 8.0 | 172.5 | 7.0 | 11.0 | 5.0 | 36.0 | 3.0 | 2.0 | 5.0 | 1.0 | 54.0 | 844.5 | 1.2 | 19.1 |
| 13C | 1.5 | 16.0 | 33.0 | 13.5 | 6.0 | 11.0 | 4.0 | 36.0 | 1.0 | 2.0 | 6.0 | 1.0 | 51.5 | 79.5 | 1.2 | 1.8 |
| 14C | 1.5 | 18.5 | 14.5 | 15.0 | 5.5 | 10.5 | 4.0 | 36.0 | 0.5 | 3.0 | 4.0 | 1.0 | 30.0 | 84.0 | 0.7 | 1.9 |

to the usual landowner activities causing local cable breakages, there were unusually frequent and heavy thunderstorms in the array area, causing a series of line group outages. Furthermore, the relocation of the NTA facilities at Lillestrøm, near Kjeller, caused outages as all equipment was moved and reconnected at the new location. One carrier system group was temporarily rerouted due to NTA investigations of irregularities on the permanent path. Table 01 summarizes outages and degraded performance of communications circuits. Subarrays are treated separately, although in many cases the outages concern groups of subarrays. Degraded performance is defined as circuits having between 20 and 200 bit errors per 16-minute intervals as recorded by the monitor printout. Circuits having more than 200 bit errors are treated as outages. It should be noted that the total hours is the sum of individual 16-minute periods when degraded or down conditions are registered. Actual error periods may be very short within a 16-minute period, but there is no way of determining the exact figure.

P. Tveitane

## P. EXPERIMENTAL ANALOG STATIONS AT NORSAR

### Short Period Analog

A short period analog station was installed at NORSAR in January 1973. The seismometer is of the same type as those used in the array (Hall Sears HS-10-1), and it is physically located in the long period vault of the subarray 05C. The data is transmitted in analog form (FM) on a special line to the NORSAR Data Processing Center, with a standard drum recording on paper (Helicorder). Fig. P1 shows the response curve for the instrument as it has been for most of the year 1973. The magnification at 1 Hz is controlled daily by inserting a calibration signal to the calibration coil of the seismometer, and it has usually been operated around 35000, with values up to 50000 during the summer. The main problem in the operation of the seismometer has been the quality of the communication line, which has caused relatively frequent breaks and repeated damage to the recording instrumentation.

The main reasons for installation of the SP analog station have been the following:

- to provide a continuous recording also covering time periods lacking in the digital recording.
- to get a recording of events causing saturation in the digital system. This frequently happens for events above $m_b$=5.5.
- to assist in the identification of local events.
- to provide the EP analysts with an overview of the larger events of the day, later phases, etc.

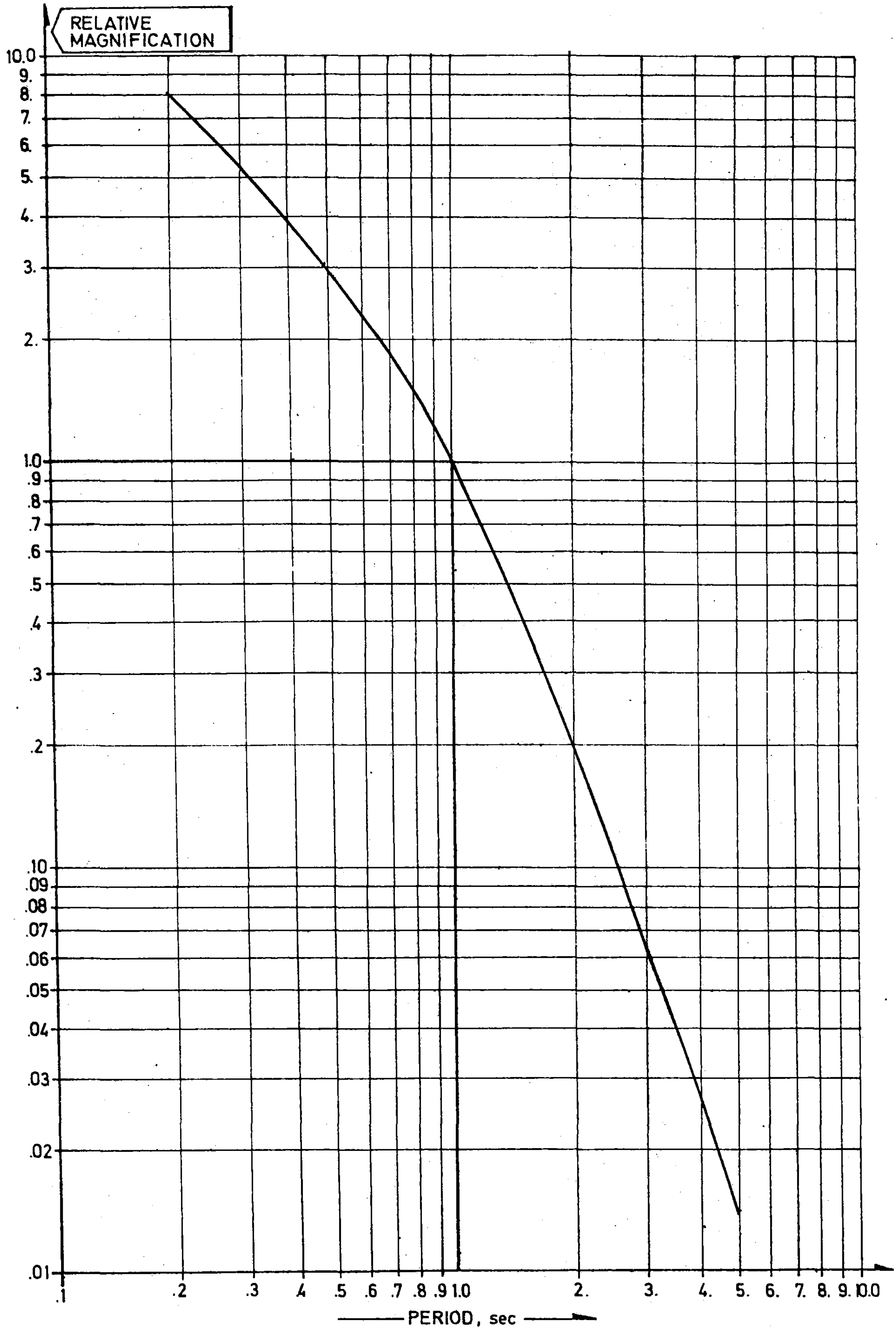



Fig. P1 Magnification of NORSAR SP Analog Station relative to magnification at 1.0 sec period.

In the evaluation of the analog station the seismograms have been read regularly and $m_b$ values computed. Fig. P2 shows a comparison between NORSAR analog and digital $m_b$, where it appears that the analog values are usually between 0.1 and 0.2 $m_b$ units above the digital (EP) estimates. This can be satisfactorily explained by a beamforming loss in the digital system, combined with the effect of the fact that 05C is a better than average subarray.

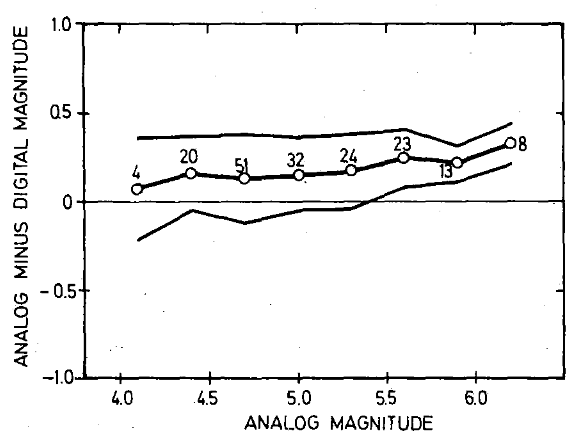



Fig. P2 Analog minus digital $m_b$ at NORSAR as a function of $m_b$. The data is averaged over intervals of 0.3 $m_b$ units, and the number of events and standard deviations used are indicated.

As part of the effort to localize local (and near-regional) events, a high pass filter with cutoff at 2.0 Hz was installed in the analog channel in October 1973. The frequency response of the system after the implementation of this filter is shown in Fig. P3. The many outages due to poor communication lines have so far prevented a full evaluation of the filter change.

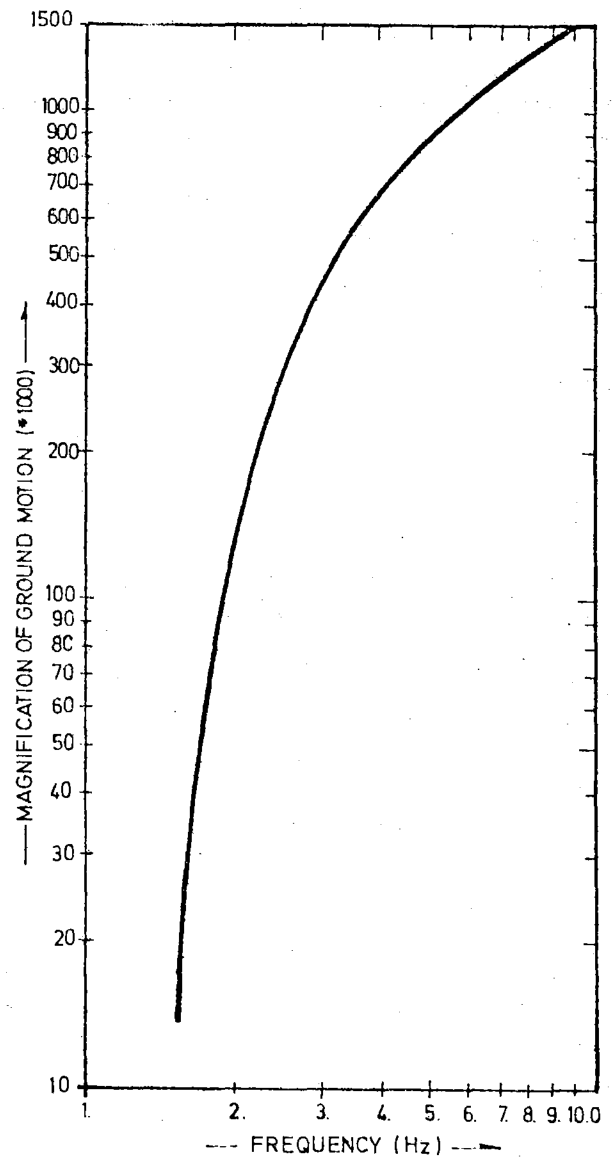



Fig. P3 Frequency response of NORSAR Analog SP station with high pass filter.

Broadband Analog (KIRNOS)

A research project has been initiated on a Nordic basis in which the aim is to compare magnitude measurements using U.S. and U.S.S.R. instrumentation, and to look at the detectability of different waves at different periods using these instruments. As a part of this project, the University of Helsinki provided NORSAR with a full KIRNOS instrumentation, type SVK-2, which was installed in the long period vault of subarray 04B in December 1973 (Pettersen 1973). The galvanometer, type GK-VIIM, and the recording drum are installed in a mobile hut located nearby. Fig. P4 gives the magnification of the Kirnos system as a function of period, and the characteristics are shown in Table P1.

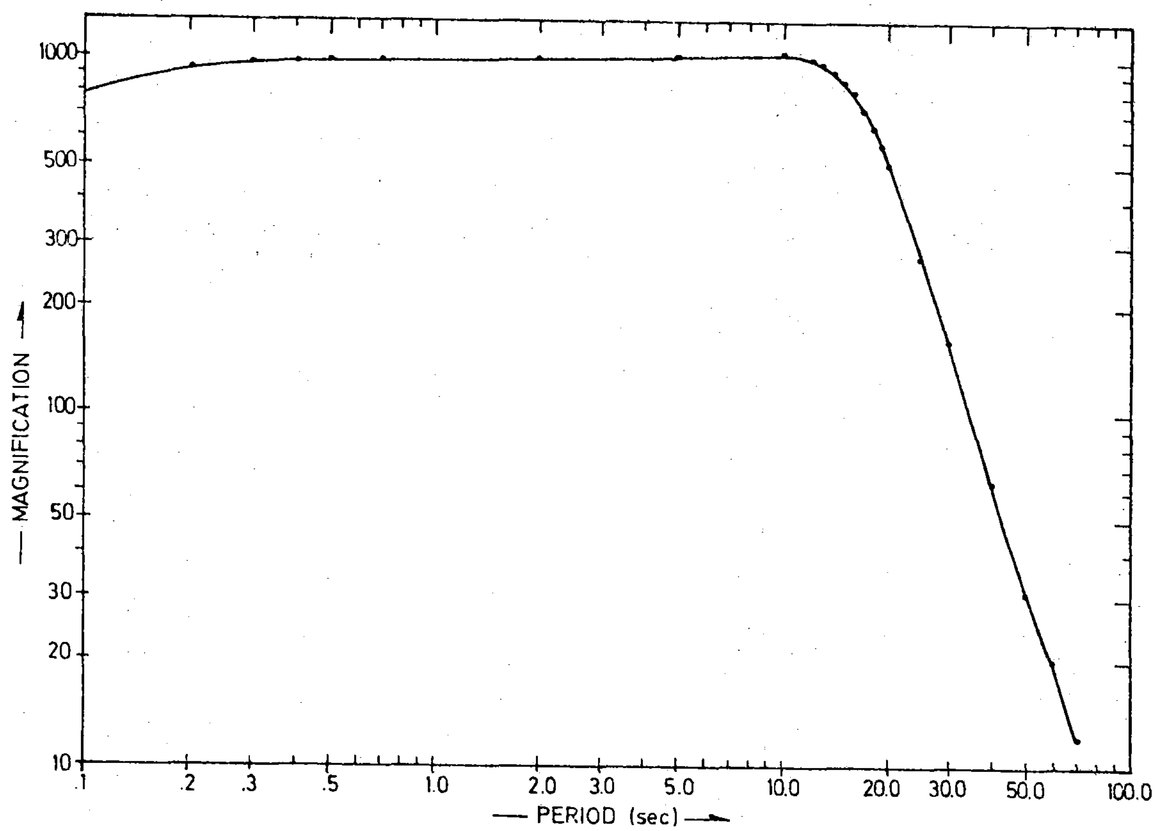



Fig. P4 KIRNOS seismograph response.

Table P1

Characteristics of KIRNOS seismometer and galvanometer.

| Seismometer | | Galvanometer | | Coupling Coefficient ($\sigma^2$) |
|---|---|---|---|---|
| Natural Period (sec) | Damping | Natural Period (sec) | Damping | |
| 15.0 | 0.4 | 1.2 | 8.0 | 0.18 |

Only a few seismograms have been obtained from the KIRNOS so far, and no real evaluation has therefore started. However, it is obvious from the records that they are completely dominated by the 6-second microseisms, and to the extent that there are several days between each time there is an identifiable seismic signal. Also, surface waves from really large events tend to contaminate the records for hours. Better performance should be expected during the summer season.

H. Bungum
A. K. Nilsen
O. Steinert

REFERENCES

Pettersen, R.: Report on a visit to Finland related to the KIRNOS project at NDPC, NORSAR Internal Report No. 4-73/74, 1973.

## Q. ARRAY MONITORING AND FIELD MAINTENANCE

This section includes a review of actions of remote array monitoring at NDPC and maintenance accomplished at the subarrays by the field technicians.

### Subarray Monitoring Schedule

The planned schedule for the remote array monitoring (AM) has been well met. Only in a few cases the monitoring routines have been delayed. A new schedule was introduced in November and is presented in Table Q1. The off-line computer requirement for AM was then reduced from an average of 34 hours per month to approx. 20 hours. The schedule for the on-line tests is unchanged.

Table Q1

Monitoring rates for AM programs.

| Biweekly | Monthly | Bimonthly | Quarterly | Annually |
|---|---|---|---|---|
| LPCAL<br>RSA/ADC Test | SLEMTEST | MISNO<br>CHANEVSP<br>SACPSP* | CHANEVLP | SACPLP |
| * Subarrays with newly overhauled seismograph amplifiers are analyzed every four months. | | | | |

### Maintenance Visits

Figure Q1 shows the number of visits to the different subarrays in the period. Excluding visits caused by troubles in the communications system, the subarrays have in average been visited 6.5 times. The large differences from average for some of the subarrays are explained mainly by power faults and cable breakages.

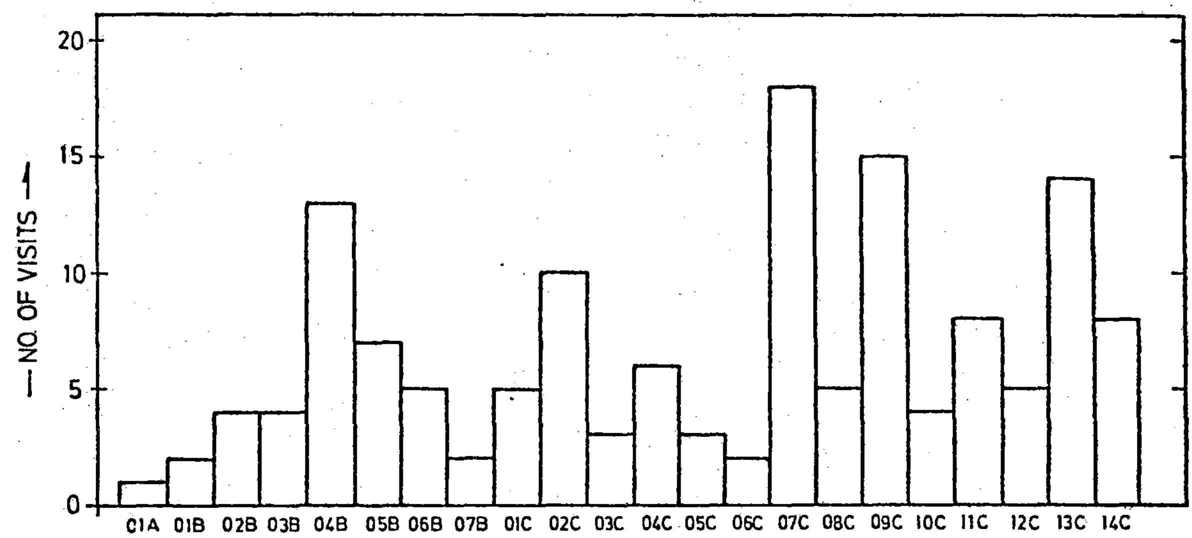



Fig. Q1 Number of maintenance visits to the NORSAR subarrays, 1 July-31 December 1973.

Preventive Maintenance Projects

Work accomplished as part of this type of the preventive maintenance of NORSAR is described in Table Q2. The work at WHVs consisted of maintenance such as painting of the wood frame, replacement of RA-5 amplifiers and control of all circuits at the site. The new RA-5s installed had been fully overhauled with new power batteries mounted.

Table Q2

Preventive maintenance accomplished at NORSAR during the period.

| Unit | Action | No. of Channels/ Subarrays | | Comments |
|---|---|---|---|---|
| | | Accompl. | Remaining | |
| SP seism. | Replacement of sensors due to damping and/or nat. freq. | 2 | None | 02B02,13C04 |
| | Adjustment of damping | 12 | None | 02B02;01C03,04; 04C01,02;07C04; 09C02,03,04; 10C03,06;13C04. |
| RA-5 | Modification of RA-5 input card | 3 | 10* | 09C06;10C03,06 |
| WHV & RA-5 | Construction maintenance | 21 | 50 | 01C;04C;09C;12C04; 13C01-04,06. |
| | RA-5 replacement | 24 | 60 | |

* 8 of these are modified for noise suppression but variable damping resistance, $R_d$, is lacking.

## Disclosed Malfunctions on Instrumentation and Electronics

Table Q3 gives the number of accomplished adjustments and replacements of field equipment in the total array with the exception of those mentioned in Table Q2.

Table Q3

Total number of required adjustments and replacements in the NORSAR data channels, 1 July - 31 December 1973.

| Unit | Charac-teristic | SP | | LP | |
|---|---|---|---|---|---|
| | | Repl. | Adj. | Repl. | Adj. |
| Seismometer | Damping | | 12 | | 2 |
| | Nat.Freq. | 2 | | | |
| | Sensitivity | | | 1 | |
| | Distortion | | | | |
| | RCD | | | 1 | 2 |
| Seismometer Amplifier | Gain | 3 | 2 | | |
| | Distortion | 2 | | | |
| | Balance | | 1 | | |
| | Filter | 1 | | | |
| LTA | Ch.gain | | 28 | | 2 |
| | Filter discr. | 3 | | | |
| | DCO | 3 | 6 | | 1 |
| | CMR | 1 | 4 | | |
| | K2 relay fault | 4 | | | |
| BE Card | | 53 | | | |
| SLEM | | | | | |
| BB gen. | | 11 | 7 | | |
| SP gen. | | 1 | 3 | | |
| LP gen. | | 2 | 2 | | |
| RSA/ADC | | 4 | 8 | | |
| EPU | | 3 | 3 | | |
| DU | | | | | |

## Malfunctions of Rectifiers, Cable Breakages

Two malfunctions on the subarray rectifiers have been reported: at 04B (transformer M2 and timer d2 burned caused by lightning, inoperative 8-10 Aug) and 04C (defect timer relay).

Cable breakages have been numerous and have occurred 22 times all over the array in all types of cables.

## Workshop Repairs

With the exception of nine RA-5s and a few SP seismometers and SLEM cards, all units removed from the field this period and the previous reporting period have been repaired The remaining units will be repaired and checked out during the winter. At present 21 SP/LTA cards with ripple and DCO faults are to be repaired at NMC. Investigations have shown that the filter ripple varies as the card is mounted in different channels. The cause is not known, but will be investigated. LTA cards with unadjustable DCO will be modified (see Table Q5). At present 144 spare LTA cards are available in the array.

## New Instruments and Facilities at NMC

A few instruments have been acquired in the period and are listed in Table Q4.

An attenuating platform for testing of LP and SP seismometers has been constructed by Teleplan A/S and is installed at NMC. An on-line communication line, 2400 baud, connecting NMC to NDPC is installed and in use,

Table Q4

NORSAR field maintenance instruments acquired in the reporting period.

| Type of Unit | Manufacturer and Type Description | No. of Units |
|---|---|---|
| X-Y recorder w/time base | Bryans 24400 | 1 |
| Digital multimeter (AC/and battery oper.) | Fluke 8000A01 | 1 |
| Gaussmeter | Alpha Scientific Inc., Model 3104 | 1 |
| Electronic galvanometer | YEW 2707 for use with "portable Wheatstone bridge" YEW 2755 | 1 |
| Portable welding transformer | NORGAS 135 | 1 |

but is not finally released by NTA. The purpose of the line is to permit pre-check of components before installation in the field and performing research using the simulated array at NMC.

## Improvements

A number of investigations were initiated during the previous reporting period to prepare lasting solutions to problems or time-consuming maintenance of certain units experienced during the operation of NORSAR. The status of these projects is commented in Table Q5.

Table Q5

Status of proposed improvements of NORSAR's field equipment.

| Subject | Action |
|---|---|
| Depression of noise in SLEM discrete inputs (DI) | Modification is under testing at 05C (modification 3b in Larsen 1973) |
| Too low surge rating of BE protection card | Modified BE-cards with 5 W wire-wound resistors is under testing at 11C on all SP channels |
| The CTV monitor triggers at low temperatures | Modified prototype is being tested at 04B |
| Trends towards negative DC offset in the SP/LTA | Original offset trimpot is replaced by 360 KΩ pot, which gives adjusting range of $\pm$135 mV (previously $\pm$30 mV). Modification is under testing at 03B and 05C. |

## Conclusion

The array is in good standard and has operated satisfactorily throughout the period. Compared with previous periods (see Steinert and Nilsen 1973 a & b) no anomalies can be reported. Due to the observed stability in both the array's SP and LP instrumentation, the monitoring schedule has been further relaxed.

The preventive maintenance program for the WHVs and RA-5s has been accomplished according to plan and will continue and be fulfilled next summer. All access roads within the array have been surveyed and with one exception (14C) all roads were in good condition.

A trend towards negative DC offsets in the SP channels, possibly caused by a permanent change in the Tchebyscheff low pss filters, has been observed. To compensate the channels offsets will be adjusted with positive bias whenever feasible.

The large number of reported faulty test generators and low channel gains are caused by lightning. The construction of the channels' lightning protection cards is under investigation.

O. Steinert
A.K. Nilsen

REFERENCES

Larsen, P.: Noise in SLEM Discrete Input, NORSAR Technical Report No. 52, NTNF/NORSAR, Kjeller, Norway, 1973.

Steinert, O., and A.K. Nilsen: Array Monitoring and Field Maintenance Report, 1/7-31/12-1972, NORSAR Technical Report No. 51, NTNF/NORSAR, Kjeller, Norway, 1973 a.

Steinert, O., and A.K. Nilsen: Array Monitoring and Field Maintenance Report, 1/1-06/30-1973, NORSAR Technical Report No. 60, NTNF/NORSAR, Kjeller, Norway, 1973 b.