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1 January – 30 June 1974

Prepared by
H. Bungum

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ABBREVIATIONS

ADC	-	Analog-to-Digital Converter
BB	-	Broad Band
BE card	-	Lightning Protection Card
CMR	-	Common Mode Rejection
CTV	-	Central Terminal Vault
DCO	-	DC Offset
DU	-	Digital Unit
LP	-	Long Period
LTA	-	Line Termination Amplifier
NTA	-	Norwegian Telegraph Administration
RA-5	-	SP Seismograph Amplifier
RCD	-	Remote Centering Device
RSA	-	Range Scaling Amplifier
SLEM	-	Short and Long Periodic Electronic Module
SP	-	Short Period
WHV	-	Well Head Vault

SUMMARY

In this second Semiannual Technical Report from NTNF/NORSAR we can report on seismological research which has been initiated within some areas previously not covered by this institution, as well as continued work on other topics. The physical operation of the array is continuing with few changes.

As a natural continuation of previous work on core phases and their precursors, a number of phases such as PKSKP and PKiKP have been analyzed in order to study the anelasticity of the inner core. Further reports are also given on Chernov random media investigations and on wave scattering effects in travel time and amplitude, followed by an outline of principal component techniques in analysis of seismic waves. Then comes a report on the P-wave amplitude variations across NORSAR, giving essential information on amplitude weighting and ranking of subarrays. Concluding these works on body waves is a report on the coda of P in terms of wave scattering theories, and an outline of a broadly based project on S wave studies.

The reports on surface wave studies include firstly one describing a recently initiated study of source mechanisms for North Atlantic earthquakes. Work on actual explosion data includes one report on non-linear instrumental response to strong long period P-waves, and one describing the continued work on m_b:M_s at NORSAR. Also, a comment on the effect of multipathing on single station group velocity analysis is given.

A report with direct relevance to the operational system at NORSAR describes the relation between false alarm rate and noise stability, whereupon the subjects change to earthquake prediction and measurement of seismicity.

The last seven reports are all related to the operation of NORSAR, including two experimental analog stations which are not physically connected to the NORSAR system.

H. Bungum

A. THE ANELASTICITY OF THE INNER CORE

Core phases traversing the inner core are well known to be relatively weak, if observable at all. Although the physical parameters in the inner core and near the inner core boundary are still less constrained than in any other region of the earth, there is at present no indication to attribute the "anomalous" attenuation of the inner core phases to the boundary in the velocity-density model. As reported in the previous Semiannual Report, models with a complicated transition zone have no observational basis anymore, following the array analysis of precursors to core phases. A single sharp boundary with a jump in rigidity and density is consistent with observations of normal modes (Dziewonsky and Gilbert 1973) and of PKiKP at short epicentral distances (Engdahl et al 1970). What remains to be investigated is the effect of anelasticity. The construction of an anelasticity model for the inner core in terms of Q for P waves and a study of some implications have recently been completed (Doornbos 1974). The Q model has been derived from spectral ratios of core phases with common source and receiver and with ray paths in and just outside the inner core. A frequency band around 1 Hz has been analyzed. In order to reduce the effect of attenuation sources (including scattering) outside the inner core, it is necessary that each two phases are chosen so that their ray paths outside the inner core are nearly like each other. This condition stresses the problem of finding suitable data. Short period NORSAR data have been used to extract the relevant pairs of phases, including (PKSKP, PKiKP), (PKSKP, PKP(BC)), (PKSSKP, PKiKP), (PKSSKP, PKKP(BC)). The array is needed in particular to separate PKSKP and PKiKP, and to identify PKSSKP. These phases are shown in Figures A.1 and A.2.

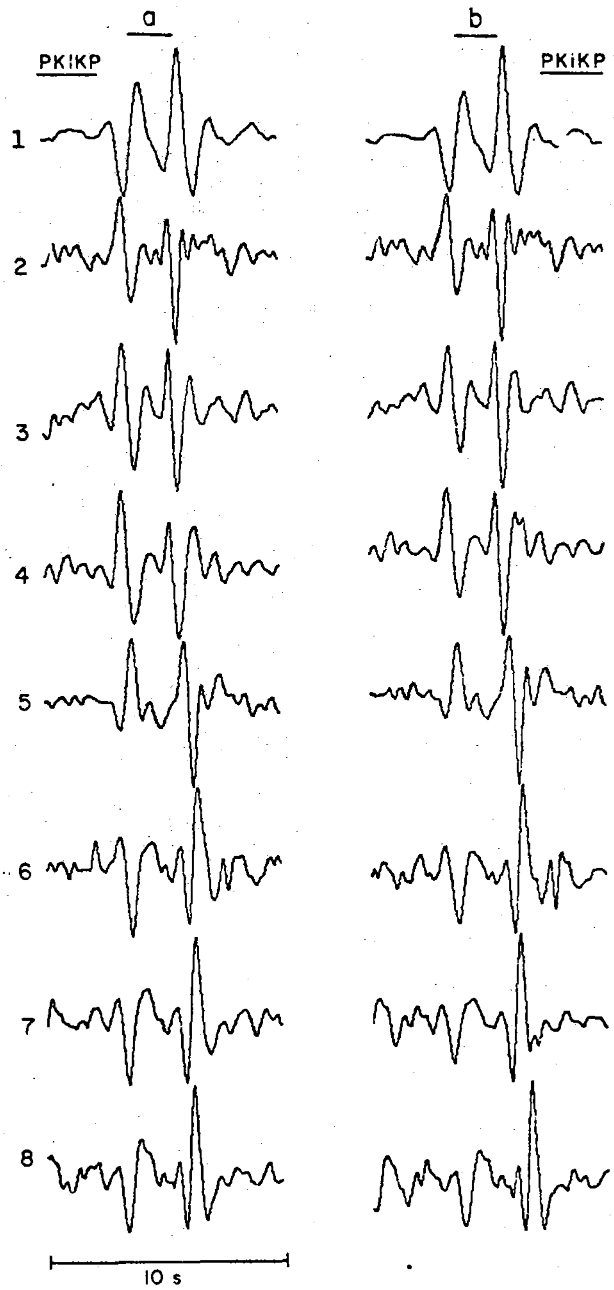

Figure A.1 Array beams steered at PKSKP(a) and PKiKP(b) from deep focus events in the Fiji Islands region. Epicentral distances from NORSAR are between 138°-141°. The traces have been normalized to peak amplitude.

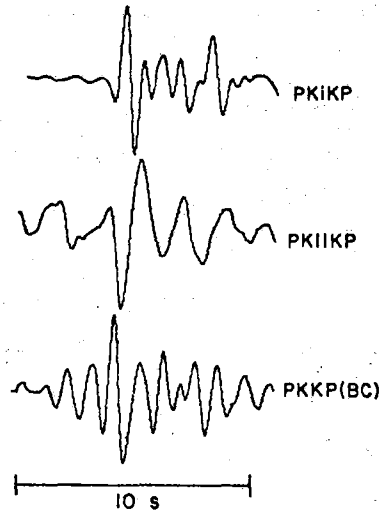

Figure A.2 Core phases from an event with or.time=4 Apr 1972, 22hr, 43 min, 6.7 sec., magn.=6.6, depth=377 km. Epicentral distance from NORSAR is 108.4°. The traces have been normalized to peak amplitude.

Some of the spectral ratios have been derived from spectra forms, but mostly the array beam should be formed, in order to reduce interfering signals and noise. Rather than using the conventional power spectrum of the array beam, I have preferred to derive the spectral ratios from the maxima of instantaneous spectral amplitudes, as introduced by Dziewonsky et al (1969) in the analysis of surface waves. It can be shown that the instantaneous amplitude at center frequency ω_o follows from

$$A(\omega_o,t) = \left|2 \int_{-\infty}^{0} F(\omega,\omega_o)e^{i\omega t} \frac{d\omega}{2\pi}\right| \qquad (1)$$

where $F(\omega,\omega_o)$ represents the filtered beam trace in frequency domain. It is convenient to use a Gaussian filter:

$$F(\omega,\omega_o) = B(\omega)\cdot\exp\{-\alpha(\omega-\omega_o)^2\} \qquad (2)$$

The parameter α should be chosen so as to compromise between the effects of time and frequency windowing. Figure A.3 gives an example of the instantaneous spectral amplitudes of PKSKP and PKiKP with α=0.35. The figure shows that in a fixed time window interference, not only of PKSKP and PKiKP, but also of PKP precursors may be important. Use of instantaneous spectral amplitudes minimizes the effect of this interference.

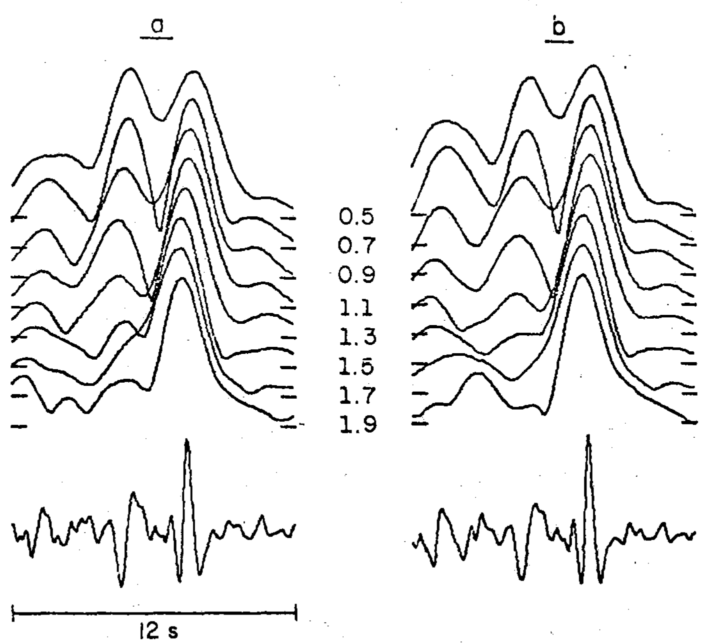

Figure A.3 Instantaneous spectral amplitudes at center frequencies 0.5-1.9 Hz, of array beams steered at PKSKP (lower trace, a) and PKiKP (lower trace, b) from a Fiji Islands event (nr. 8, Figure A.1). The traces have been normalized to peak amplitude.

Under certain assumptions we obtain from the j-th event

$$(t_1^*-t_2^*)_j = a_j + \pi \int_{SC} Q^{-1}(r)\ dt \qquad (3)$$

where the travel time integration is through the inner core, a_j includes terms arising from ray path differences outside the inner core, and the differential attenuation $(t_1^*-t_2^*)_j$ follows from the spectral ratio. The above system of operations can be discretized and inverted. The results corresponding with three different velocity models for the earth are shown in Figure A.4, where it is emphasized that the value Q=1000 in the lower part of the inner core does not rest on firm observational evidence. In this part Q values between limits 600 and 2000 are still possible with the present evidence.

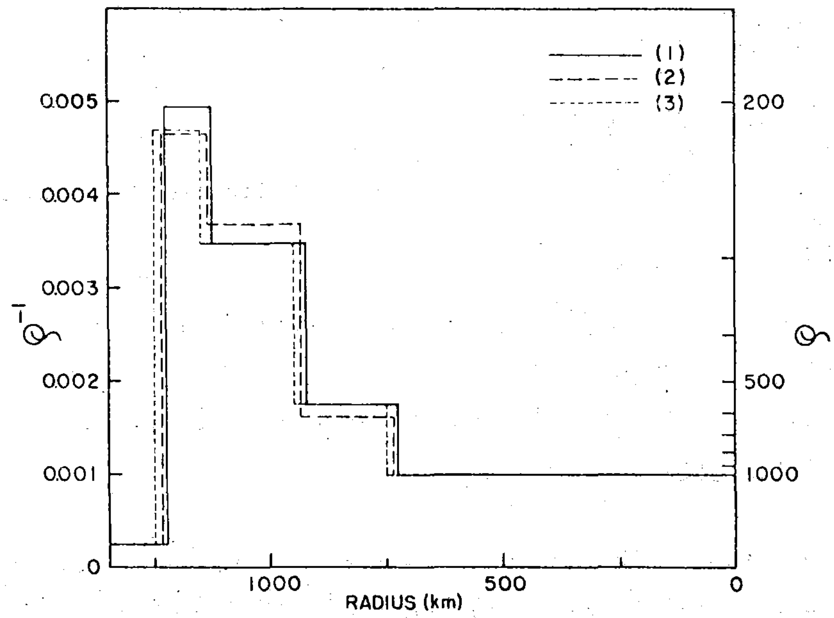

Figure A.4 Q_α at 1 Hz in the inner core, corresponding with different velocity models: (1)=Buchbinder 1971 (Bull. Seism. Soc. Am., 61, 429), (2) Jeffreys-Engdahl 1968 (Ph.D. Thesis Engdahl, Saint Louis University), (3) Gilbert et al 1973 (Proc. Nat. Acad. Sci., 70, 1410). In the lower 750 km of the inner core a Q value 1000 has been suggested.

The low Q values of the models in Figure A.4 have several implications. First, it is suggested that the temperature at the inner core boundary is close to the temperature of inner core material (presumably iron) and that partial melting occurs in at least part of the inner core. Second, the amplitudes of inner core phases, in particular phases like PKSSKP and PKSKP, are much reduced. Both computational and observational results predict that PKSSKP is observable only in exceptional cases and that PKSKP is too small to be observed.

D.J. Doornbos

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B. A CHERNOV RANDOM MEDIUM MODEL

In the theory of body wave propagation in random media, the medium is characterized by its extent, and the mean square and autocorrelation of the refractive index. Based on a Gaussian type correlation function, Chernov (1960) has been able to establish a set of equations which makes it possible to estimate these parameters. The main assumptions are that the medium is statistically isotropic and homogeneous with small velocity fluctuations caused by large-scale inhomogeneities, the extent of the medium is large compared to the extent of the inhomogeneities and finally that the Rytov approximation is valid.

Important results of Chernov (1960) are the formulae for the transverse autocorrelation for phase and amplitude as a function of spatial lag. A drawback here is that the distance (ℓ) between instruments should not be much greater than the correlation distance (a). However, limitations of the above type of the Chernov theory have been removed by replacing approximately analytical integral solutions by numerical ones.

Another problem is that the observational data, i.e., relative travel time and logarithmic amplitude (logamplitude) of P-waves recorded across NORSAR, are likely to reflect not only forward wave scattering effects, but also deterministic effects like a locally dipping Moho. The latter effect is not accounted for in the Chernov (1960) theory, and unless removed may introduce a serious bias in the estimate of the random medium parameters.

Considering the crust and upper mantle beneath NORSAR as a Chernov medium, a least squares procedure has been utilized for estimating the relevant parameters. The starting point is to minimize the expression:

$$F = tr(S_1 - \Sigma_1)^2$$

where tr denotes trace and S_1 and Σ_1 are (N times N)-matrices, where N is number of instruments used. The S_1 and Σ_1 matrices are

$$S_1 = C \cdot S \cdot C' \qquad \text{and} \qquad \Sigma_1 = C \cdot \Sigma \cdot C'$$

where S is the observed covariance matrix for P-wave phase or logamplitude, while Σ is the theoretical covariance matrix. Σ is a function of the correlation distance $\underline{a}$, the mean square refractive index $\overline{\eta^2}$, the extent of the medium $\underline{L}$, and the measurement error θ. C is an N by N matrix and has the form

$$\begin{bmatrix} 1-\frac{1}{N} & -\frac{1}{N} & \cdots\cdots & -\frac{1}{N} \\ -\frac{1}{N} & 1-\frac{1}{N} & & -\frac{1}{N} \\ \cdots & \cdots & & \cdots \\ \cdots & \cdots & & \cdots \\ -\frac{1}{N} & -\frac{1}{N} & & 1-\frac{1}{N} \end{bmatrix}$$

C' is the transpose of C. The C matrix is introduced in order to remove deterministic wave propagation effects. For further details on this estimation procedure, see Christoffersson (1974).

For a subsection of NORSAR consisting of subarray 01A and 01B, the parameters (a, η, L, θ) which minimize F have been estimated (Berteussen et al, 1974), and it is found that the phase and logamplitude data give essentially the same results (see Table 1). The value obtained for $\underline{a}$ is approximately 15 km. The product $\overline{\eta^2} \cdot L$ occurs in almost all the expressions used; it is therefore difficult to separate the effect of these two parameters. That is, it is difficult to determine whether the medium is thick with small velocity variations or the medium is thin with large velocity variations. The results obtained so far indicate that L is at least 250 km and in this case η has a standard deviation of approximately 1.0%. For an array of the size considered here, aperture around 25 km, the Chernov theory is able to explain 74% of the variations in logamplitude and 94% of the variations in travel time anomalies. These values will certainly be diminished for a greater array where deterministic effects will have relatively more influence. It should also be stressed that the type of data used is amplitude and phase (measured at 0.7 Hz) of the very first cycle in the P-wave train.

As mentioned before, it is difficult to distinguish between a thick medium with small velocity variations and a thin medium with large variations in velocity. This point is also illustrated in the results obtained by different scientists. For example, for LASA Aki (1973) found L = 60 km and STD of η = 4% (Table 1). Capon (1974) obtained practically a two times larger value for L (136 km), but half as much velocity variations (STD of η = 2%). For NORSAR we again have doubled L ($L \geq 250$ km) but also reduced the velocity variations with a factor of two (STD of $\eta \approx 1\%$). These last values should, however, not be compared directly with those obtained at the LASA since the type of data and method of analysis are different. There may, of course, also be significant differences between the medium under LASA and that under NORSAR.

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E.S. Husebye
A. Dahle

TABLE 1

Calculated Chernov (1960) medium parameters for structures beneath the NORSAR and LASA arrays.

SOURCE	TYPE OF DATA			CHERNOV MEDIUM PARAMETERS		
	Array	Phase-Amp.	Freq. (Hz)	std. of refractive index (%)	Correlation Distance (km)	Extent of Medium (km)
This study	NORSAR	Phase	0.7	0.8	13.5	$\geq$ 250.0
This study	NORSAR	Amp	0.7	0.9	16.7	$\geq$ 250.0
Aki (1973)	LASA	Phase & Amp	0.6	4.0	10.0	60.0
Capon (1974)	LASA	Phase & Amp	0.8	2.0	12.0	120.0

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C. WAVE SCATTERING EFFECTS IN TRAVEL TIME AND AMPLITUDE

The small-scale random variation in the body wave velocity which causes random fluctuations in travel time and log-amplitude are accounted for by the following two models:

$$T_i = T_o+\vec{R}_i\vec{U}+t_i+\varepsilon_i \qquad i = 1,\ldots,n \qquad (C.1)$$

$$\log A_i = \log A_o+a_i+\varepsilon'_i \qquad i = 1,\ldots,n \qquad (C.2)$$

T_i is the observed travel time at the i-th seismic station with position vector $\vec{R}_i$ in a local cartesian coordinate system. T_o is a constant. $\vec{U}$ is the travel time gradient (slowness), t_i is the random fluctuation in travel time and ε_i is measurement error or noise. $\log A_i$ is the observed logarithmic amplitude at the i-th station, $\log A_o$ is a constant (level), a_i is the amplitude fluctuation and ε'_i as before measurement error or noise.

Analytical expressions for the quantities t_i and a_i are given in Chernov's (1960) theory on scattering of acoustic waves in a random medium, which is also considered to be approximately valid for seismic P-waves. The uniform plane wave model formerly accepted, treated the terms $t_i+\varepsilon_i$ and $a_i+\varepsilon'_i$ simply as uncorrelated measurement errors. Correlation is thus a key word in the study of scattering effects.

Using very accurately determined travel time (and log-amplitude) data from 10 events filtered in time domain around 0.7 Hz, the correlation between the quantities $t_i+\varepsilon_i$ at the 132 stations comprising the NORSAR array were computed. Assuming this correlation rotational symmetric in accordance with the Chernov (1960) theory, we obtain a correlation function of the type depicted in Fig. C.1. A similar correlation function is also established for the amplitude fluctuations (Dahle et al, 1974).

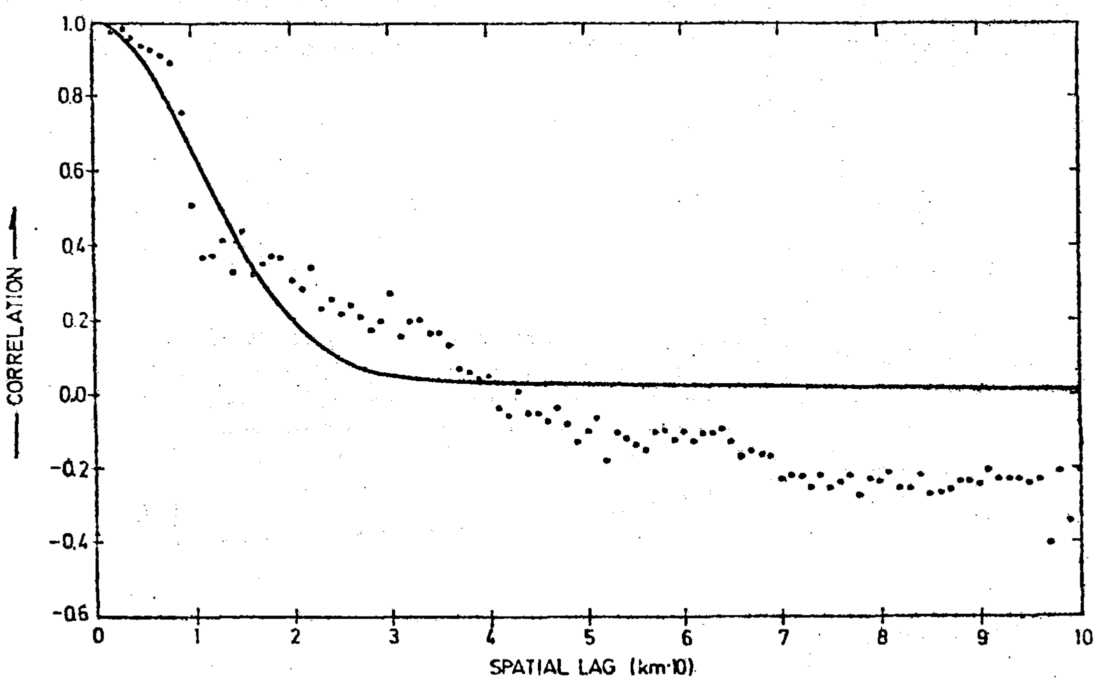

Fig. C.1 Estimated correlation function for travel time together with the theoretical Chernov (1960) function (solid line).

In order to test the importance of the t_i (or a_i) term, least squares linear estimation and prediction were used (Heiskanen and Moritz, 1967). This procedure takes advantage of the covariance between fluctuations in the anomalies $(t_i+\varepsilon_i)$ shown in Fig. C.1.

The theoretical covariance matrices estimated from Chernov's analytical expressions are given as function of the average size of the inhomogeneities causing scattering (correlation distance) and a dimensionless quantity called "wave parameter" which is proportional to the depth of the inhomogeneous medium. The difference between squared observed minus predicted travel times (or logamplitudes) for a network of stations relative to the conventional plane wave residual variance is shown in Fig. C.2 for a typical event. In fact, the main part of the anomalies seems to be explainable in terms of correlated fluctuations superimposed on a plane wave front as actually done in Chernov (1960) and Dahle et al (1974). The presence of correlated

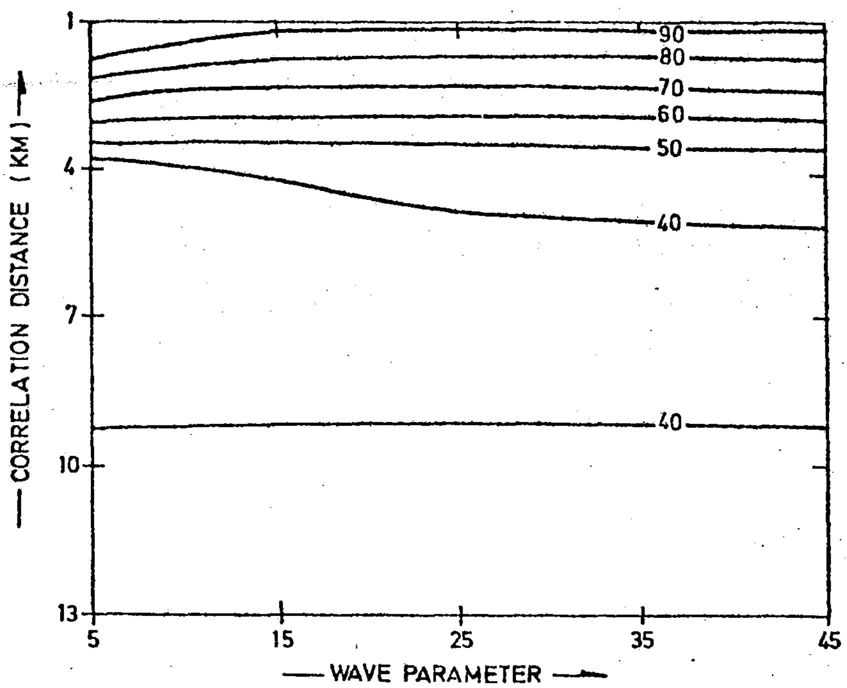

Fig. C.2 Contour plot showing per cent variance in observed-predicted travel times relative to the conventional plane wave residual variance.

residuals implies that slowness estimates for small-scale arrays are highly unreliable, but that a transformation of the observed travel times into uncorrelated observations improves such estimates. For further details on these topics, see Dahle (1974) and Dahle et al (1974)

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D. PRINCIPAL COMPONENT TECHNIQUES IN ANALYSIS OF SEISMIC WAVES

Beamforming or simple delay-and-sum processing is extensively used in analysis of P-waves recorded by an array of seismometers or geophones. When the underlying assumptions of well-equalized noise levels and identical signals between instruments is correct, the corresponding gain in signal-to-noise ratio (SNR) is optimum. In practice, these restrictive signal and noise models are not valid, thus degrading the final signal estimate. Recently, Christoffersson and Jansson (1974) have developed a time series analysis theory for more generalized signal models, and its practical applicability has been demonstrated by Christoffersson and Husebye (1974).

In a continuation of the above work the emphasis is on a spatial interpretation of generalized seismic signal models. The basic idea here is that an array of M sensors in principle represents an M-dimensional sampling of an incoming P wave. For example, if the signals are identical between sensors, then the signal space is one-dimensional. On the other hand, if the signals are somewhat different, the best one-dimensional signal estimate, that is the array beam using optimum sensor weights, corresponds to the main principal components of the geometrical space spanned by the observations. Another example is the polarization filter used in analysis of 3-component seismometer records (Madariaga, 1967). Such a filter essentially passes one-dimensional signals, and rejects two- and three-dimensional signals, as demonstrated in Fig. D.1. In fact, the polarization filter has proved very powerful in analysis of S and surface wave records.

For further details on the above topic, the reference is a recent paper by Husebye et al (1974).

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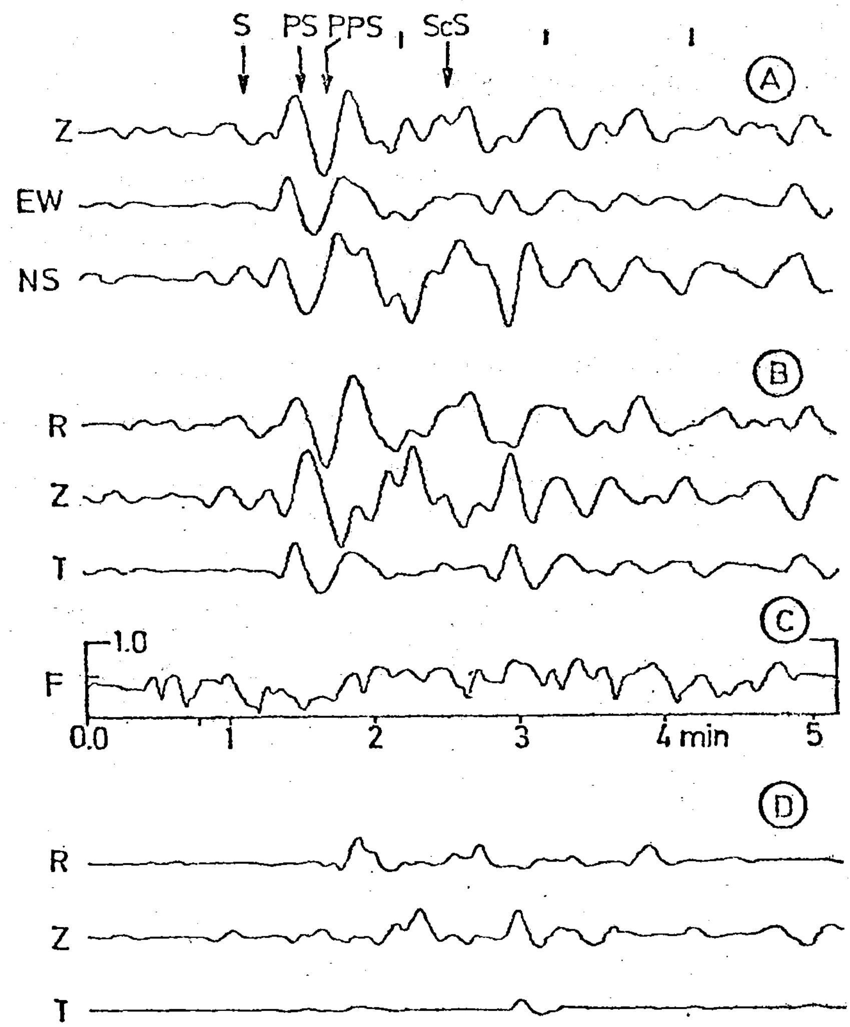

Fig. D.1 3-component records from the NORSAR subarray 01A of an earthquake in the South Atlantic 30 Sep 1971. The epicentral distance is 62.3° and the expected arrival time of different types of S-phases are shown. Section A shows the original records, section B shows the same records after rotation, i.e., the R-component coincides with the P-wave angle of incidence. Section C gives the filter weight and also the time scale of the records, and section D is the polarization filter output. Signal window is 20 sec and the projection axis remained constant during the filtering operation. The filter rejects a significant part of the signals so the particle motion is elliptical, say a combination of S and P polarized waves. Also, a phase shift between vertical and horizontal components may be important here.

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E. P-WAVE AMPLITUDE VARIATIONS ACROSS NORSAR

It has been found that there is a large amplitude variation for P-wave signals crossing the array, and that this variation approximately follows a lognormal distribution (Ringdal et al 1972). The purpose of this study has been to measure these variations, and to find to what degree they influence the performance of the Detection Processor (DP). The data used has been established by measuring subarray and array beam amplitudes on P-phases detected at NORSAR during 1972 and 1973. All events which were not clipped and had a signal-to-noise ratio (SNR) above 6.5 have been used. Totally this gave 964 events. In Table E.1 is listed for each DP beam (Anonymous 1973) where any data is found and the amplitude loss for the different subarrays relative to the best subarray. The last row in Table E.1 gives the average performance for all beams. As seen from the table, the array beam amplitude has also been calculated and compared with the best subarray. This makes it possible to calculate the average signal correlation (ρ_s) between the different subarrays, when one assumes that the array beam loss is caused solely by lack of correlation. With the ρ_s value known and with the additional assumption that the noise is uncorrelated from one subarray to another, it is possible to calculate expected SNR loss on the array beam for the case where one or more subarrays are excluded from the beamforming. The procedure has been for each beam to calculate the expected SNR when only the subarray with the samllest amplitude is excluded, when the one with second smallest is also excluded, and so on until only the subarray with the highest amplitude is left. It if found that for more than 90% of the DP beams three or more subarrays could be excluded without decreasing the SNR on the beam. For 20% of the beams, ten or more subarrays could be excluded. There is, however, very seldom any significant gain in SNR obtained by deleting the subarrays with smallest amplitude. Only for 5% of the DP beams is it possible to obtain an SNR gain of 0.4 dB or more, while for 23% of the cases a gain of 0.2 dB or more is possible. Figure E.1 illustrates a case where a gain of 0.15 dB can be obtained by deleting 9 subarrays, while Figure E.2 illustrates a case where no gain is obtained. As can be seen from Table E.1 the amplitude pattern may vary very drastically from one beam to another. It is, for example, seen that the subarray which in average has smallest amplitude (no. 22) for beam 11 and beam 13 is the very best subarray (both beams are pointing towards southeastern Alaska).

Figure E.3 shows the expected average performance if one permanently excludes a certain number of subarrays. Because of the varying amplitude pattern, it is seen that as an average one is always going to have a certain loss even by excluding only the very worst subarray. Excluding only no. 22 would, for example, in this case give a loss of 0.1 dB. If both no. 22 and no. 6 (the one with the second smallest amplitude) are excluded, one is on an average going to have a loss of 0.2 dB in detectability. Excluding half of the subarrays is going to give a loss of 1.9 dB in average, but for some particular regions this would, of course, have a much worse effect.

The two main subjects left to analyze in this work are the effect of varying signal correlation and the possibility that the amplitude pattern varies as a function of magnitude. Also figures like Figure E.3 are to be established for several regions.

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REFERENCE

Anonymous (1973): System Operation Report, NORSAR Technical Report No. 62, NTNF/NORSAR,Kjeller, Norway, 20-24.

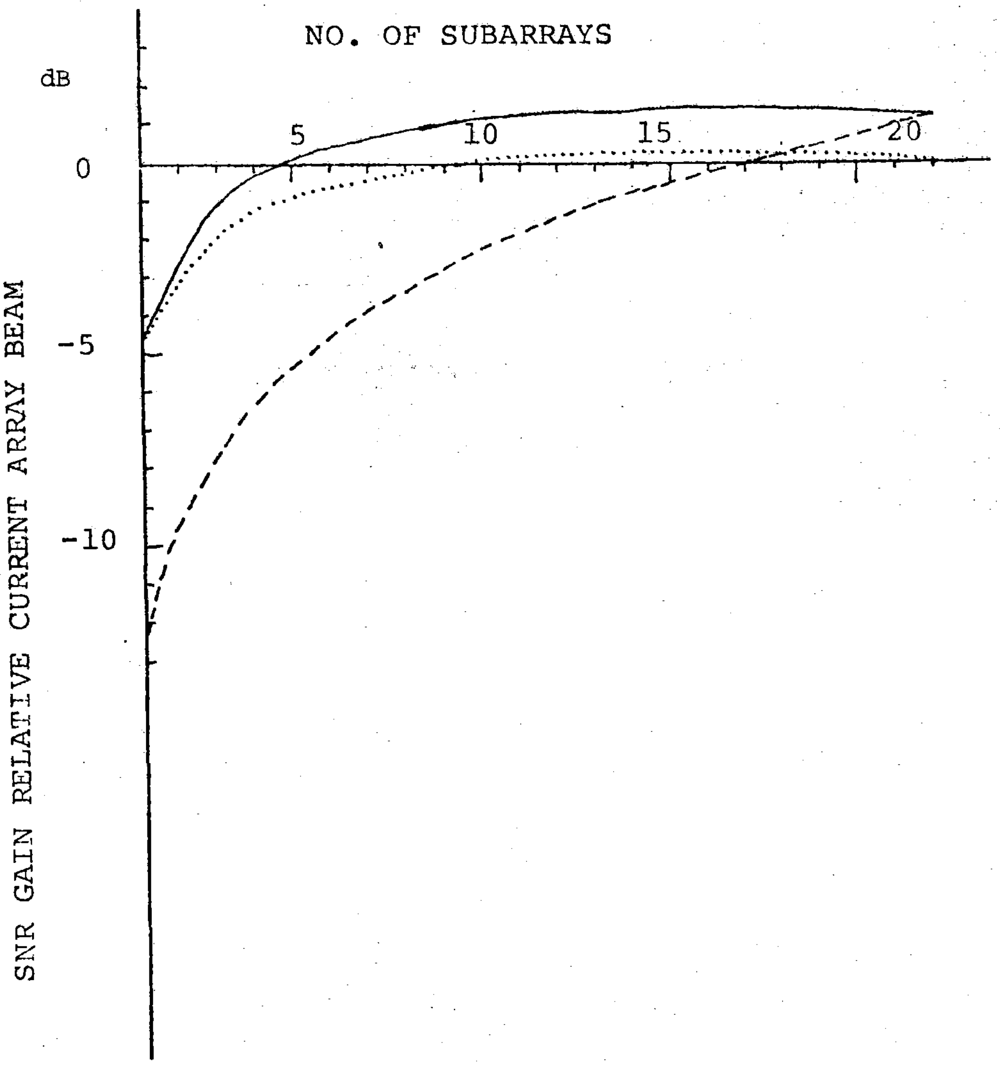

Figure E.1 Expected performance for beam 91 as a function of number of subarrays.

Beam 91 is steered towards South of Honshu, Japan (29N, 139E). The dashed line shows the theoretical $\sqrt{N}$ signal-to-noise performance for the case that all signals are equal in shape and amplitude. This line ends at a gain of 1.2 dB, which implies that the currently used array beam has an average amplitude loss of 1.2 dB. The fully drawn line shows the performance if all signals were equal in shape (correlation=1.0) but had the amplitude pattern listed for beam 91 in Table 1. It is seen that the best subarray is only 4.5 dB below the current array beam. In this case a beam made from the 5 best subarrays is seen to give the same SNR as the current array beam. The dotted line shows the expected pattern and with an average signal correlation of 0.75. In this case the 10 best subarrays will give the same SNR as the beam. Using the 15 best subarrays is going to give a gain of 0.15 dB.

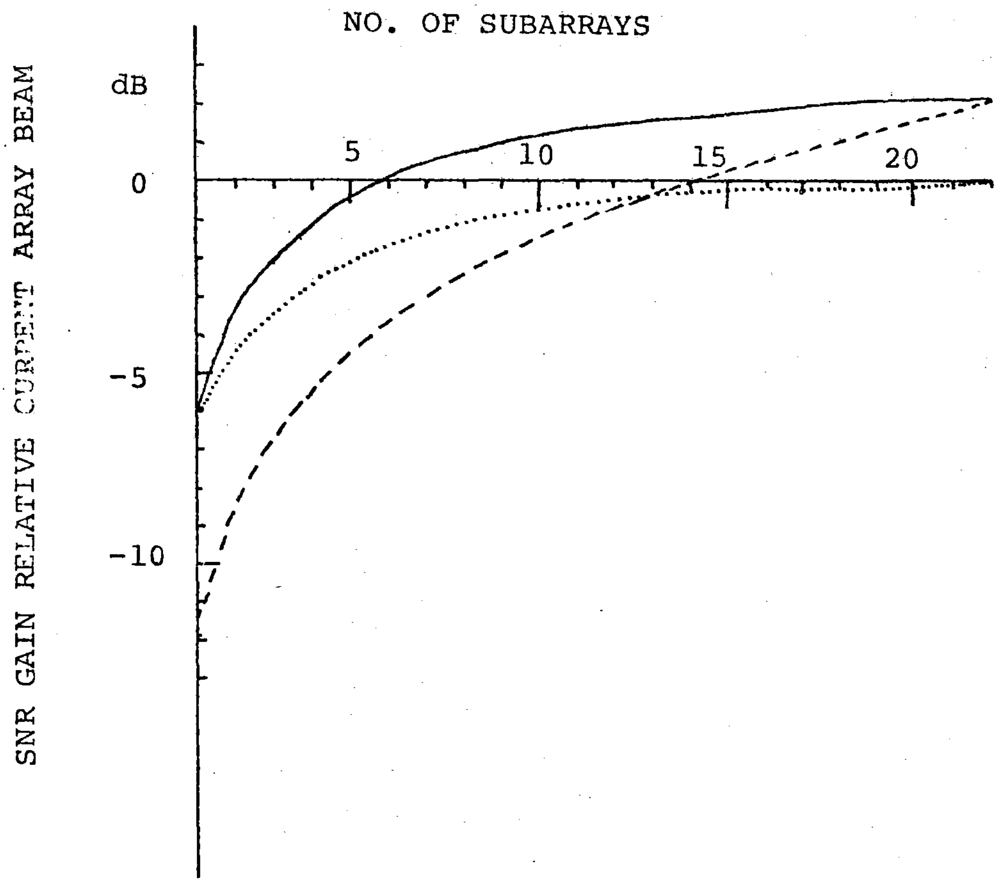

Figure E.2 Same as Figure E.1 for beam 175 pointing towards northern Colombia (7N, 73W). In this case the difference in amplitude between the best and the worst subarray is 10 dB (for beam 91 it is 17.7dB) and it is seen that no gain is obtained by excluding the bad subarrays.

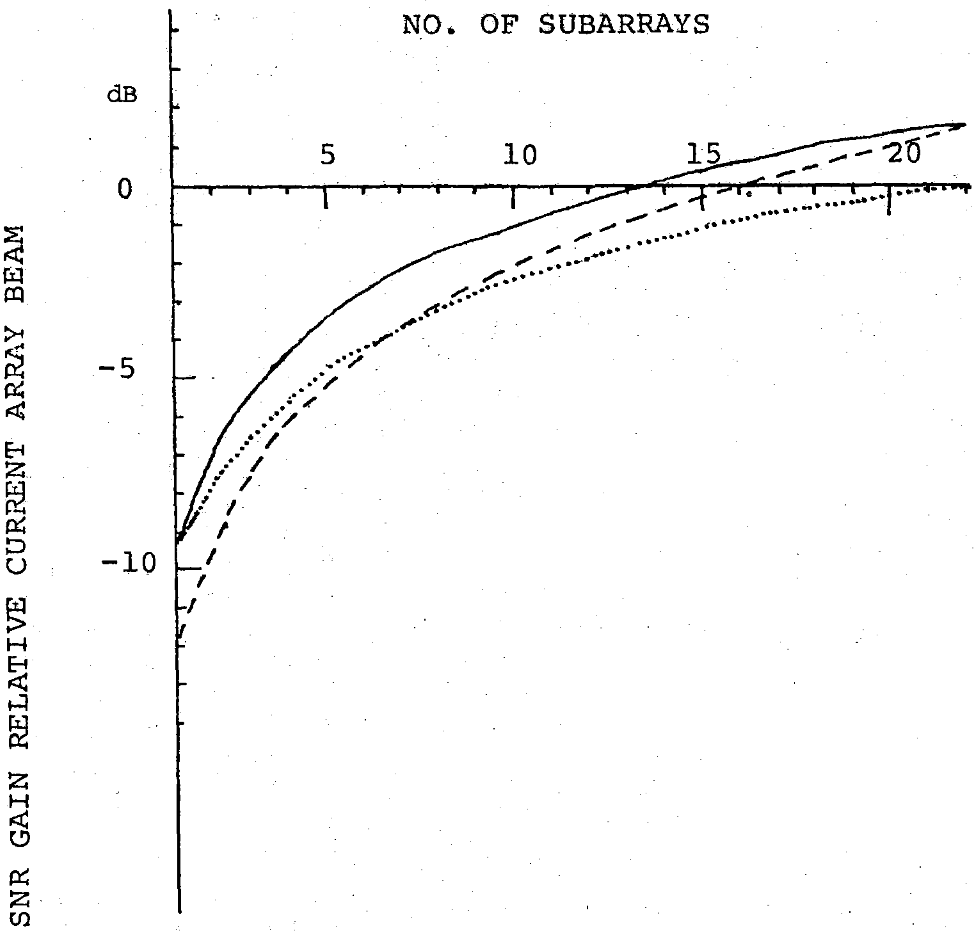

Figure E.3 Same as Figure E.1 for the average of all beams (last row Table 1). In this case the difference in amplitude between the best (no. 13) and the poorest (no. 22) subarray is only 4.5 dB, and it is seen that the observed performance gets closer to the theoretical $\sqrt{N}$ performance. If only the 11 best subarrays were used, the average amplitude loss is seen to be 2.1 dB.

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
6	3	9	5	10	13	10	3	4	5	12	9	2	0	9	5	8	8	10	8	8	8	[illegible]	8
9	2	6	3	9	11	8	1	5	4	8	6	3	1	12	5	6	7	10	12	5	5	4	7
11	1	7	5	9	6	9	7	5	5	5	4	5	4	12	10	4	7	8	7	5	9	0	8
12	0	5	6	12	10	6	2	6	8	7	8	4	0	12	8	5	6	12	11	4	8	1	7
13	3	9	6	13	8	9	9	6	7	8	7	8	5	12	12	7	7	9	8	5	10	0	9
15	1	7	6	11	11	7	3	3	8	6	7	4	2	9	2	3	7	10	10	6	7	4	7
16	3	10	8	11	11	11	0	6	3	4	5	5	4	7	6	3	4	7	5	10	7	6	8
17	0	8	8	17	10	7	6	8	8	6	7	4	2	9	3	2	8	8	12	8		6	8
20	6	6	7	9	6	11	1	4	4	5	2	5	4	8	8	5	6	8	3	6	4	4	9
21	13	14	6	9	10	14	5	9	6	6	0	2	0	8	8	4	7	6	3	3	6	6	7
23	14	13	7	13	13	15	4	9	7	8	0	3	0	10	8	5	7	8	3	5	9	5	8
24	14	14	5	12	12	13	5	9	8	7	0	2	1	11	8	5	6	6	2	4	8	7	8
25	8	15	2	11	9	12	11	13	2	2	1	3	3	10	9	4	11	8	6	1	4	5	9
26	11	15	2	14	6	13	14	15	5	5	5	5	1	11	9	10	11	12	15	2	6	6	9
27	9	11	3	8	7	8	12	13	1	2	3	4	1	10	11	11	11	14	12	3	3	6	8
29	5	8	0	2	10	10	9	15	5	7	3	8	6	11	14	11	3	13	15	11	5	9	9
31	13	15	4	10	6	13	14	15	3	5	6	6	1	11	9	8	10	13	13	3	6	7	10
32	9	13	4	10	5	10	12	16	3	8	3	4	0	8	7	6	8	13	11	4	5		8
33	8	10	3	6	4	8	14	14	3	3	4	2	1	10	8	8	6	13	13	4	4	15	9
34	6	11	0	2	9	9	13	19	3	0	3	5	4	10	14	9	8	14	17	9	6	9	9
35	8	13	1	4	4	5	10	15	3	1	2	1	1	9	11	8	9	14	14	6	3	7	7
36	5	9	0	3	12	12	8	14	3	6	4	8	9	13	14	13	2	10	16	13	7	11	9
37	5	9	0	1	10	10	8	18	4	5	4	9	7	14	16	12	0	9	16	13	6	11	8
42	7	7	1	5	11	11	6	10	3	5	2	5	6	11	9	10	2	9	13	12	8	11	9
43	7	7	1	6	10	12	4	10	2	4	4	5	5	11	9	10	1	6	12	10	7	9	8
48	3	4	8	4	9	6	7	3	4	6	2	11	10	6	8	9	8	0	9	6	10	8	8
50	8	11	0	3	9	12	5	11	3	6	5	6	2	11	9	10	5	7	11	12	12	12	8
52	10	13	1	6	9	14	9	13	8	9	5	5	0	10	11	11	11	9	14	15	16	17	11
53	8	8	0	8	11	13	6	12	7	10	7	5	2	12	15	14	12	6	13	13	15	17	11
55	14	10	9	0	11	18	16	10	[illegible]	15	6	16	16	8	10	11	15	10	13	15	14	18	12
56	9	7	8	1	6	7	11	7	8	9	1	13	6	0	5	7	5	3	12	8	8		9
58	9	10	0	8	10	14	8	14	9	10	8	4	2	13	16	14	13	7	14	14	17	18	11
60	8	6	9	0	15	5	12	2	4	10	2	6	2	1	3	8	6	11	14	8	10	11	9
62	8	7	8	0	12	16	12	12	9		5	18	15	10	8	7	11	8	9	15	15	17	10
63	8	8	1	9	12	15	7	12	7	8	7	6	4	15	17	14	14	5	13	12	16	15	11
64	7	4	0	8	12	15	6	8	3	6	3	5	3	14	16	14	11	3	12	9	16	11	9
65	8	1	2	10	9	14	8	3	0	2	1	7	2	13	12	14	9	2	8	2	8	4	8
70	8	4	2	9	10	13	7	4	1	1	4	4	3	12	12	9	9	5	9	7	14	12	8
71	8	4	3	10	11	14	8	5	0	4	4	5	3	12	12	12	10	5	10	6	13	11	9
73	6	6	6	0	8	9	7	4	6	10	7	12		6	6	3	1	2	8	8	6	8	8
74	8	8	7	0	10	8	7	8	8	8	6	8	9	8	10	7	6	4	7	8	6		10
75	9	6	6	11	11	14	8	7	0	4	9	6	2	14	12	12	9	7	10	7	15	12	9
76	9	6	7	11	11	15	8	6	1	5	9	6	1	15	12	13	10	9	10	8	16	14	9
77	16	9	2	3	7	12	15	9	5	11	7	7	0	12	5	15	9	12	14	9		14	12
78	9	7	7	12	10	13	9	6	0	3	9	5	3	14	12	12	10	12	11	10	13	14	10
79	16	12	10	15	16	16	12	9	0	5	14	6	2	18	15	17	13	14	12	9	15	18	12
80	12	8	9	13	10	15	10	7	0	4	10	7	3	15	13	13	12	13	12	11	13	15	11

Table E.1 (Sheet 1 of 4)

Average subarray and array beam (AM) amplitude loss in dB for all NORSAR Detection Processor (DP) beams for which data were available. Information about the different beams is to be found in Anonymous (1974).

BEAM NO.	SUBARRAY NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	AB
81	14	13	7	9	16	21	15	10	5	10	7	5	0	14	17	15	16	12	12	13	15		14
83	7	4	8	0	8	7	5	2	7	9	6	13	9	10	5	4	1	1	2	7	2		8
84	9	9	7	11	8	12	8	5	0	2	7	6	3	13	12	13	12	12	11	10	12	13	10
86	13	10	10	14	9	10	11	7	0	6	10	5	1	14	10	13	11	13	10	11	13	18	11
87	13	9	8	12	12	14	10	8	3	8	6	4	0	15	13	17	14	17	8	12	11	16	11
89	8	8	10	11	7	10	11	0	5	8	8	7	11	8	7	8	8	7	7	11	6	12	11
90	6	7	8	13	7	14	9	1	1	3	4	4	7	8	9	10	10	5	5	12	8	12	9
91	7	6	5	13	7	13	10	6	2	3	7	2	0	13	11	14	12	11	10	12	14	18	9
92	7	7	4	10	6	10	8	2	1	3	7	1	2	9	11	11	13	9	7	12	10	13	8
93	12	8	4	7	12	17	11	5	2	6	4	0	1	14	12	13	8	15	6	8	6	14	9
95	9	2	3	0	1	11	3	7	11	7	7	10	8	9	11	6	4	1	4	9	5	5	7
97	10	8	5	12	11	13	12	6	0	5	3	3	1	12	9	11	9	13	6	10	2	10	9
98	8	6	6	9	9	12	9	3	1	4	4	2	3	11	10	10	8	12	4	10	6	13	9
101	9	8	2	3	3	7	2	6	12	14	8	10	4	13	8	6	4	3	1	5	2	4	7
102	10	3	3	2	1	9	3	8	10	10	7	12	7	9	9	5	5	1	1	10	3	3	7
103	8	12	5	10	9	11	10	6	1	10	4	4	0	9	7	10	9	11	4	9	1	11	9
104	0	4	3	3	6	2	3	8	11	9	6	4	1	1	13	8	7	10	7	3	8	7	6
105	3	2	3	2	0	1	2	10	9	13	5	4	1	3	7	6	5	6	6	0	2	4	5
106	9	11	5	11	11	11	11	6	4	6	3	0	1	11	8	10	12	12	8	15	3	12	10
107	9	13	5	11	11	13	10	7	3	7	3	2	0	10	6	10	11	15	6	11	2	12	9
110	3	5	7	8	4	5	5	10	12	8	9	3	2	2	11	8	7	7	9	2	8	5	9
112	5	12	7	9	9	10	7	4	2	7	4	1	4	10	6	5	10	7	3	8	2	10	8
113	1	2	1	2	2	5	2	8	9	10	5	1	2	0	11	7	5	11	13	7	14		5
115	4	11	9	9	7	9	6	5	3	3	3	3	6	10	5	3	11	3	2	8	3	10	8
116	9	13	11	14	11	14	12	7	13	6	3	0	4	14	9	7	12	11	7	13	4	12	11
119	3	8	5	6	6	3	4	9	9	9	11	5	4	0	10	6	4	10	7	1	5	6	9
120	7	12	10	11	9	12	7	5	4	3	3	4	8	11	6	6	12	5	3	7	0	7	9
121	5	10	10	10	9	10	8	4	3	4	4	3	8	11	7	5	12	7	3	8	2	10	9
122	9	13	4	8	6	11	9	9	0	3	8	7	6	4	4	7	3	6	6	12	7	10	8
123	7	12	3	6	5	12	11	10	0	2	9	5	6	1	3	7	6	3	3	12	8	8	7
124	6	8	0	5	3	12	11	8	6	8	7	2	6	1	5	8	9	4	8	12	9	8	8
125	7	7	2	6	4	11	16	10	9	9	6	5	4	0	7	9	13	6	7	12	9	9	9
126	5	6	6	3	8	9	10	6	10	7	5	7	7	2	5	9	11	7	13	12	9	11	12
127	0	5	8	10	10	4	6	9	13	9	10	10	2	2		7	5	5	8	2	9		8
129	7	11	0	4	7	13	9	8	2	5	7	6	2	3	2	8	7	8	8	9	6		9
131	5	6		4	8	8	6	7	6	5	4	2	0	4	7	3	8	8	8	7	4	9	8
132	2	2	6	7	9	8	4	5	9	5	9	5	2	4	13	4	9	8	7	4	7	4	8
134	8	10	15	14	8	7	6	6	4	3	5	10	11	8	5	3	10	8	4	3	0	10	8
135	6	9	5	3	3	9	2	5	3	1	4	3	3	5	0	9	8	13	7	7	4		6
136	9	9	4	7	10	10	5	7	2	0	7	5	5	5	3	9	7	7	9	12	8	8	10
137	7	10	2	7	5	10	8	7	1	0	4	3	0	2	2	5	5	6	7	9	6	6	7
138	1	9	6	8	4	12	16	9	3	4	5	1	1	4	4	5	7	0	3	6	6	10	5
139	3	7	3	6	6	10	13	7	2	2	1	1	0	4	7	7	11	7	7	6	5	4	7
140	0	3	3		5	6	3	4	7	2	7	4	3	5	8	5	7	5	11	7	4	3	9
141	6	6	3	9	7	8	8	7	12	10	4	6	0	1	11	7	6	7	10	6	12		10
142	8	3	5	5	7	5	2	4	3	3	8	3	0	5	9	3	3	0	5		8	6	5
143	5	10	7	11	9	9	6	9	2	2	2	5	8	5	0	8	4	11	11	14	7		9

Table E.1 (Sheet 2 of 4)

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
144	8	13	9	13	8	14	6	13	2	5	5	8	7	8	0	4	5	10	11	18	4		9
145	5	7	4	3	7	11	11	9	4	1	5	3	1	4	5	9	7	4	11	8	8	10	9
148	6	14	13	7	6	9	2	9	1	4	3	10	3	5	1	6	4	7	11	15	4	7	8
149	6	9	7	4	3	10	2	9	1	3	3	5	0	3	1	3	2	2	8	8	6		6
150	5	11	8	23	7	9	13	8	3	5	2	2	0	3	6	11	11	9	13	6	8	11	8
151	5	6	12	8	9	5	3	8	11	9	13	5	3	7	12	5	9	10	9	1	7	9	8
152	10	5	9	7	10	2	1	4	10	6	10	6	7	5	10	0	4	8	12	1	10	13	7
155	6	12	7	5	4	7	0	7	2	3	1	8	2	5	4	4	7	6	10	6	3	7	7
157	7	9	5	0	9	12	9	8	2	3	3	8	0	9	7	8	5	3	6	10	7	10	8
159	4	10	9	9	5	10	10	7	3	5	2	2	0	3	8	7	9	4	9	2	6	12	8
161	6	8	9	10	8	3	3	9	10	8	13	5	3	8	10	2	8	9	11	1	7	10	9
162	5	7	11	7	6	1	2	6	11	10	11	5	4	7	8	3	9	8	9	1	7	10	9
164	11	8	12	10	8	5	0	7	11	7	11	12	8	9	15	6	7	7	4	2	14	11	9
165	8	6	10	6	5	9	6	7	9	5	7	8	7	5	6	3	10	10	11	2	2	10	10
166	10	11	10	4	5	5	6	6	7	6	5	6	1	3	2	2	6	8	10	0	3	8	7
167	10	6	12	9	5	7	5	6	7	5	8	8	5	4	6	3	13	9	12	0	2	9	8
168	11	6	9	5	5	5	3	5	6	10	3	8	1	6	2	3	9	10	10	2	3	6	8
169	9	11	10	5	5	4	5	7	8	10	4	7	0	3	3	2	8	14	13	5	5	7	7
170	8	10	9	7	5	5	4	10	7	10	6	10	0	3	1	2	5	13	13	11	7	7	9
171	12	13	9	5	9	9	12	11	4	0	3	7	2	10	9	11	12	4	10	4	10	11	10
172	8	10	5	1	12	10	15	5	5	7	2	5	5	10	9	11	15	9	12	4	12	11	10
175	1	1	10	7	4	5	3	6	9	5	10	3	9	7	8	2	11	10	11	8	6	10	8
177	9	9	4	6	6	6	12	10	0	3	3	5	0	10	9	11	9	9	11	10	6	13	10
178	9	8	6	2	10	6	12	6	3	7	2	3	0	11	8	9	13	6	9	4	8	12	9
179	12	9	7	5	15	11	15	8	4	8	0	8	6	13	9	15	16	11	11	4	12	15	10
181	7	9	0	4	4	13	2	9	10	10	5	6	8	6	10	9	7	8	9	7	8	.	7
182	5	9	8	11	7	6	1	3	11	9	10	9	6	8	8	3	4	2	6	5	8	10	8
183	15	6	5	5	10	12	14	9	4	4	1	7	4	14	7	14	15	13	8	4	11	15	10
184	16	7	6	4	13	9	19	9	5	9	0	11	5	14	4	12	13	14	17	6	11	15	11
186	3	0	1	7	1	6	4	7	9	6	3	2	6	3	9	4	11	0	6	4	8	2	5
187	11	3	5	3	8	8	10	6	6	4	2	2	1	11	6	11	13	7	4	2	8	15	9
188	14	6	8	8	15	14	16	11	5	5	0	11	7	16	9	15	17	16	12	5	11	14	11
189	2	2	5	7	4	9	8	10	8	5	0	6	4	5	10	10	16	1	6	4	5		8
190	7	4	11	8	5	14	13	11	13	9	8	0	6	5	9	7	14	7	12	10	11	10	10
191	3	8	10	7	7	4	3	0	6	6	6	8	6	8	8	5	6	6	12	6	6	11	8
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210	15	12	12	13	8	10	6	6	10	8	13	16	14	8	12	9	11	0	9	12	13	8	10
213	7	5	9	2	0	4	5	4	11	8	8	6	2	1	5	2	1	2	2	8	5	11	6
215	13	7	11	5	5	9	6	5	9	6	11	11	13	8	12	7	8	0	9	12	12	6	11
220	5	6	6	1	4	5	6	9	11	8	6	3	3	4	7	3	3	3	5	6	6	8	7
221	6	9	10	4	8	10	7	14	10	8	3	0	4	9	7	6	6	5	9	6	9	8	9
222	12	4	9	11	2	3	8	7	12	16	14	10	9	10	5	12	0	3	6	6	4	12	14

Table E.1 (Sheet 3 of 4)

BEAM NO.	SUBARRAY NUMBER																						AB
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
223	4	6	6	0	7	6	5	14	9	13	10	1	0	6	5	6	6	6	6	5	10	6	9
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227	5	3	2	3	5	15	5	15	13	11	9	2	1	10	0	3	8	9	9	10	9	8	9
229	7	5	13	9	3	10	6	1	13	13	16	10	7	5	8	0	1	4	4	6	6	1	9
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317	6	13	14	8	3	9	5	6	6	6	4	0	11	3	17		6	7	4	4	10	10	9
318	0	10	7	7	12	6	13	6	13	11	10	10	14	8	14	10	6	10	5	11	5		10
	7	8	6	7	8	9	7	8	6	7	6	6	5	8	8	7	8	8	8	8	7	9	9

Table E.1 (Sheet 4 of 4)

F. P CODA STUDIES

The irregular wave trains which follow well-known phases on short period seismograms represent meaningful information about the total seismic environment; Jeffreys (1962) has described the body wave coda as the greatest outstanding difficulty in the interpretation of seismic signals. Cleary and Haddon (1973) and Cleary, King and Haddon (1974) recently proposed an interpretation in terms of scattering by small-scale random irregularities in the crust and upper mantle which also account for the so-called precursors to PP reported by Bolt et al (1968) and several other workers. Coda wave trains recorded at NORSAR from distant events ($90^{\circ} \lesssim \Delta \lesssim 110^{\circ}$) are being analyzed in great detail in order to map approach directions (azimuth and slowness) of resolvable constituent energy bursts as a function of time. The data set of some 12 events exhibits great variability, and this in itself is evidence in support of a scattering-type interpretation.

Preliminary analysis results lend further weight to the scattering interpretation. In Figure F.1, the slowness of consecutive 15 second data windows from the coda of an event in the Molucca Passage is plotted as a function of arrival time relative to both P and PP. Also plotted is a theoretical curve for energy scattered or reflected asymmetrically at or near the free surface in the diametral plane through source and receiver. Jeffreys-Bullen tables were used in the construction of this curve, with details of large secondary arrivals taken from the model SMAK1 of Simpson, Mereu and King (1974). Notwithstanding the limitations of this 2-D representation, the measured slownesses (azimuths were all within $\pm 20^{\circ}$ of the P azimuth) are fully consistent with the scattering interpretation. It is also apparent from this figure that for this particular travel path (Philippines to Norway), the most energetic part of

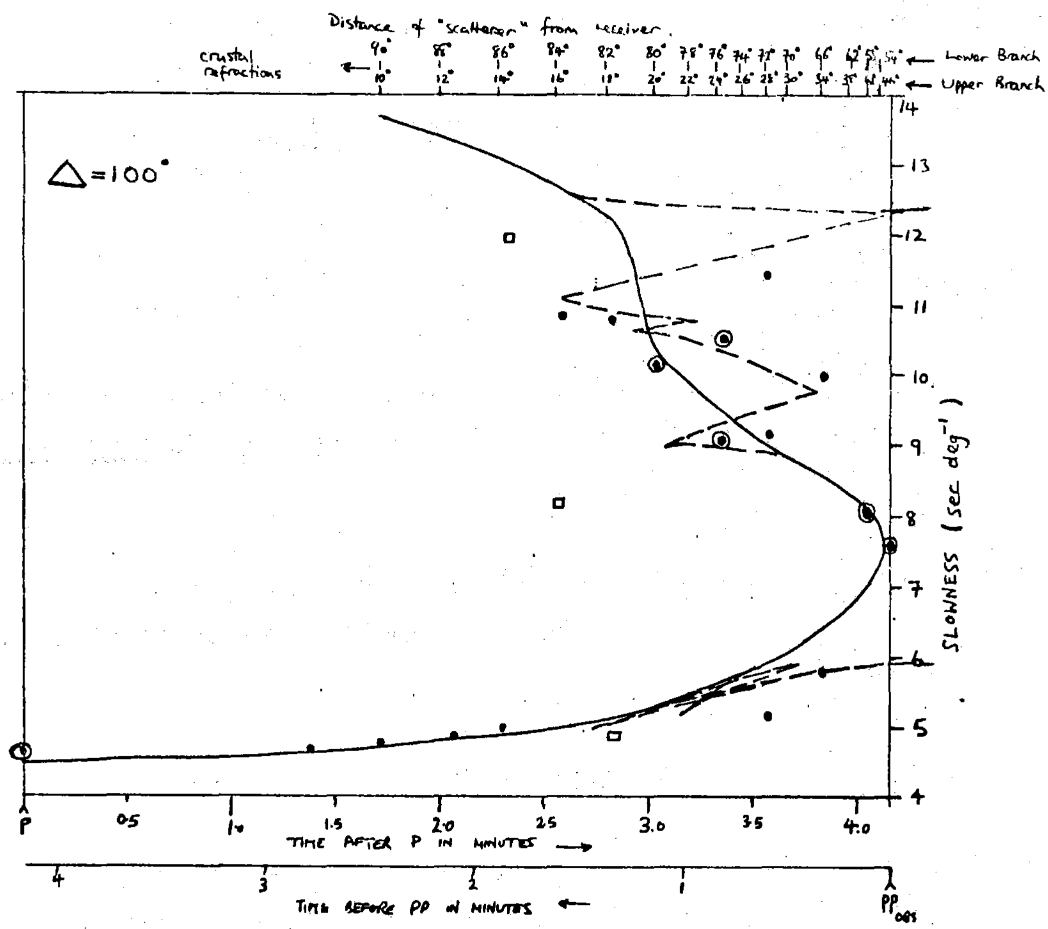

Figure F.1 Observed slowness values for 15 second windows from coda of an event in Malucca Passage (Δ~100°) compared to theoretical minimum time curve. Theoretical curve drawn by eye through JB values, with details of triplications taken from Simpson et al (1974). Dots mark energy peaks, open squares significant subsidiary peaks. Dots within circles are peaks $\gtrsim$ 16 dB.

the coda is dominated by waves scattered in the vicinity of the Ural mountains (~20° from NORSAR) and focused by the upper mantle velocity structure. Interestingly, the results presented by Cleary et al (1974) suggest that scattering in the vicinity of the Urals also dominates the coda of the Novaya Zemlya events recorded at Warramunga in Australia.

coda of the Novaya Zemlya events recorded at Warramunga in Australia.

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G. S WAVE STUDIES

A broadly based project directed to exploiting the well-recorded long period S (and associated SS, SSS, PS, PSS, ScS, PcS, etc.) and surface waves at NORSAR for studies of earth structure has been initiated. Various processing methods are being utilized, including high-resolution f-k analysis, polarization filtering and iterative cross-correlation. Long-term objectives include:

1. The localization of velocity variations, both radial and lateral, within the mantle,
2. The delineation of crustal structure (using converted phases), and
3. The identification of manifestations of the presence of anisotropic layers within the upper mantle.

With regard to the 3rd item, Crampin and Taylor (1971) and Crampin (1974) detail those consequences of aligned anisotropy which are most likely to be observed; these consequences include the generation of Love waves by atmospheric explosions. A preliminary investigation has revealed that the LP records from a large atmospheric explosion in China on 17 June 1974 exhibit convincing evidence for the existence of Love wave energy. In Figure G.1, three-component data is plotted a) as recorded, b) after rotation in both the horizontal and vertical planes, and c) after application of a polarization filter (to rotated data). A detailed analysis is proceeding.

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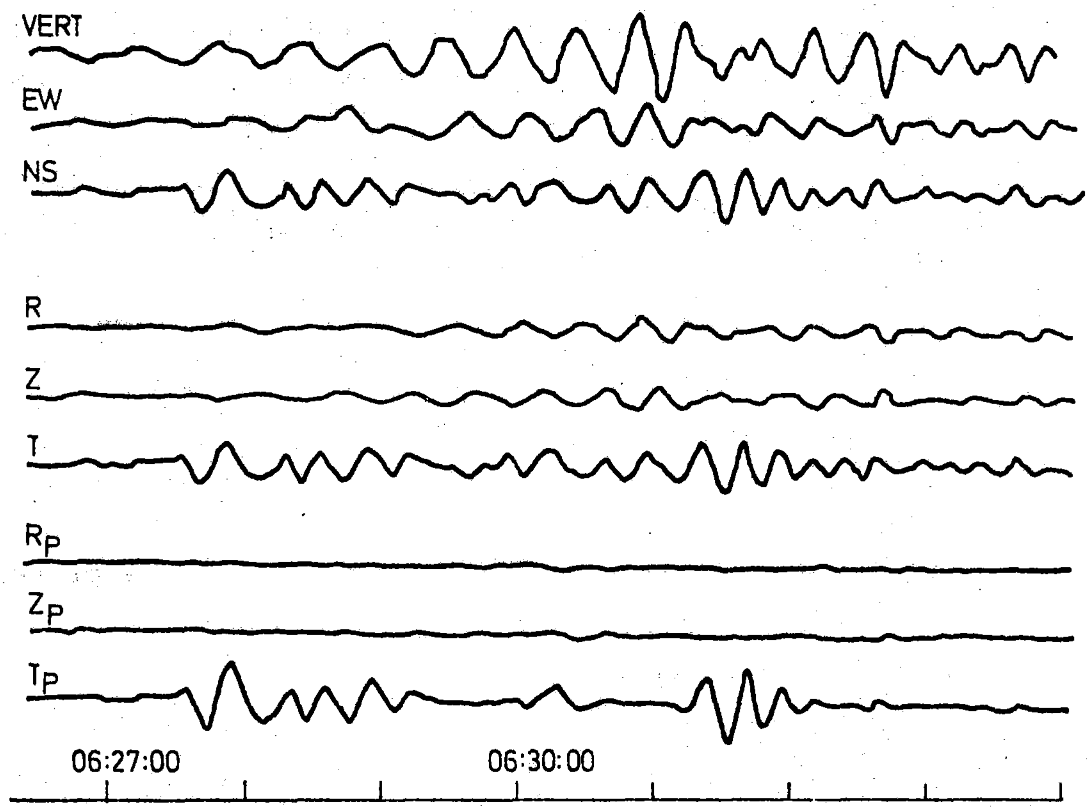

Figure G. 1 Records from LP instruments at subarray 13C of surface waves from atmospheric explosion on 17 June 1974, 05.59.53. R, Z and T are rotated components; subscript P indicates trace has been polarization filtered.

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H. MECHANISM STUDY OF NORTH ATLANTIC EARTHQUAKES

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

The mechanism of intraplate earthquakes occurring in the Norwegian Sea between the Mohn's Ridge and the Norwegian coast was discussed by Husebye et al (in press) in relation to geological and geophysical data from the area within the context of plate tectonics. Their discussions suggest the following alternative hypotheses for their mechanism.

(1) The post-opening marginal subsidence; in this case, we expect a normal faulting with fault strikes parallel to the coast.

(2) The intra-plate stress which appears to have the horizontal compressive axis parallel to the direction of plate motion. In this case, we expect a thrust faulting with fault strikes perpendicular to the direction of plate motion or a strike-slip faulting with the pressure axis parallel to the direction of plate motion.

(3) The seismic zone in the Norwegian Sea, especially the belt which continues southward as an apparent extension of the Knipovich ridge, may be a plate boundary.

As shown schematically in Fig. H.1, if the mid-Arctic ridge spreads faster than the Mohn's ridge, we expect right-lateral strike slip along the Knipovich ridge as well as along its extension into the Norwegian Sea. Two fault plane solutions published by Lazareva et al (1965) in this zone are right-lateral strike-slip along fault with the North-South strike, consistent with this hypothesis.

4) If the Mohn's ridge is spreading faster than the mid-Arctic ridge, we expect left-lateral strike-slip along the extension of the Knipovich ridge.

The surface wave method can give us an accurate determination of focal depth of an earthquake if the fault plane solution is known (Weidner and Aki, 1973). We can also determine the phase velocity and attenuation of surface waves along the path from an epicenter to a station if the fault plane solution is known. Once the phase velocity and attenuation are known for various parts in the region of our interest, we can determine the source factor of amplitude and phase spectra for any earthquake in the area. If we have both Love and Rayleigh wave source spectra for a few different azimuths, we can probably make a reliable determination of the focal mechanism, seismic moment and focal depth. Additional data from body waves, such as the pP-P time difference and the sense of first P motion at crucial directions, would be helpful to increase the accuracy of the determinations. The outcome of the above studies - the dispersion, attenuation, focal depth, seismic moment and focal mechanism - are useful quantities for discussing the tectonics of the North Atlantic.

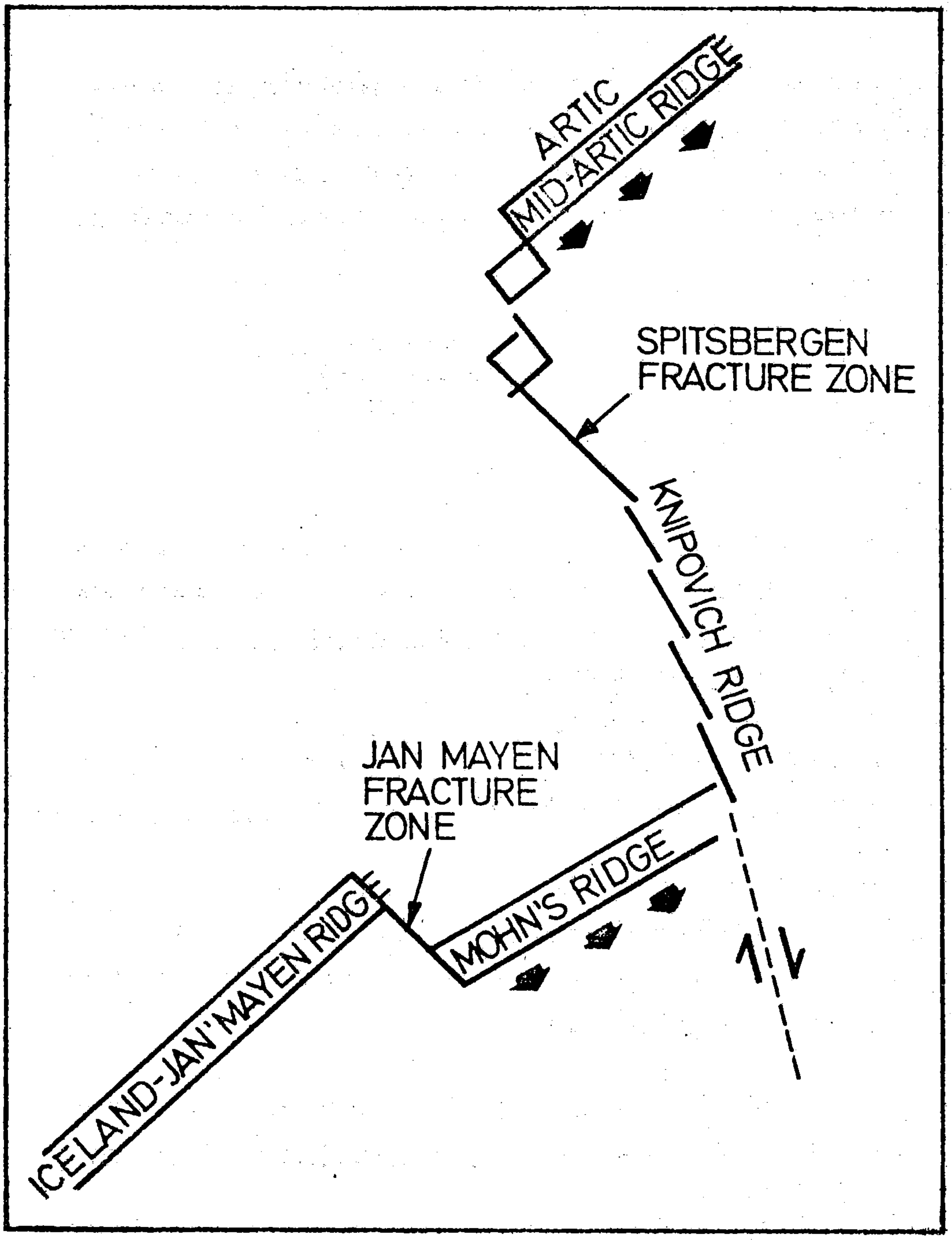

Fig. H.1 Schematic view of the principal spreading axis in the North Atlantic.

The necessary software for utilizing the surface waves in focal mechanism studies is now available at NORSAR, and has already been tested on two earthquakes on the Mohn's ridge and Mohn-Knipovich Ridge (Aki and Husebye, 1974).

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I. LONG PERIOD P FROM NOVAYA ZEMLYA EXPLOSIONS

Routine analysis of long period P waves recorded at NORSAR after two large Novaya Zemlya explosions in 1973 revealed that the signal pulses exhibited unsystematic variations in size and shape both between events and within the array aperture for single events. This is in marked contrast with long period P phases from earthquakes (of much lower m_b) at similar distances. Records of selected vertical channels recorded after the explosion of 27 October and an earthquake at a similar distance are plotted in Figure I.1 for comparison purposes. All short period channels recorded after the explosions (12 September and 27 October) are severely clipped, since ground motions of up to approxi- 10 μm at 1 second period are involved. The variability of the long period P wave signals suggests that an instrumental instability is involved, and consultation with colleagues at Seismic Data Analysis Center (SDAC) and Lincoln Laboratory revealed that equivalent anomalous behavior has been observed in LASA recordings of large NTS explosions. The problematic 'signals' are a manifestation of a non-linearity in the response of the LP amplification system to the very large SP ground motions. The size of the ground motions involved precludes the possibility of testing for the non-linearity experimentally, but the manufacturers have provided confirmation of the anomalous behavior. Consequently, LP signals recorded when the corresponding SP signals are severely clipped should be treated with extreme caution.

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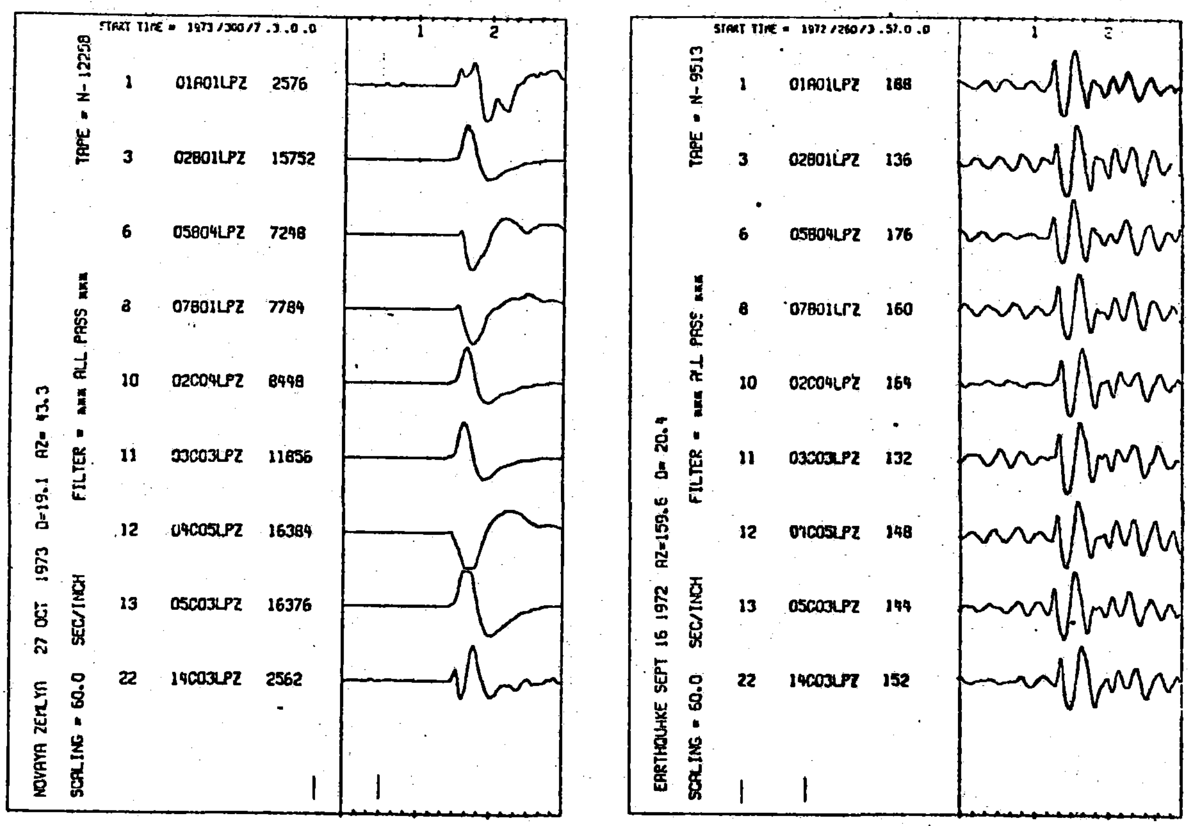

Figure I.1 Selected LP vertical channels after Novaya Zemlya explosion of 27 October 1973 (left) and earthquake of 16 September 1972 (right).

J. $m_b:M_s$ AT NORSAR

The full NORSAR array has now operated for about 3½ years, during which time more than 50 events have been recorded which we presume to be underground nuclear explosions. This is enough data to facilitate a more detailed study (see also Filson and Bungum 1972) of the discrimination capability of NORSAR in various regions, and emphasis is put on the $m_b:M_s$ method which is generally accepted as being the best discriminant available. The region for which most data have been accumulated is Central Asia, from where an $m_b:M_s$ plot is shown in Figure J.1. The distribution includes 44 earthquakes and 26 presumed explosions, and linear regression lines have been estimated

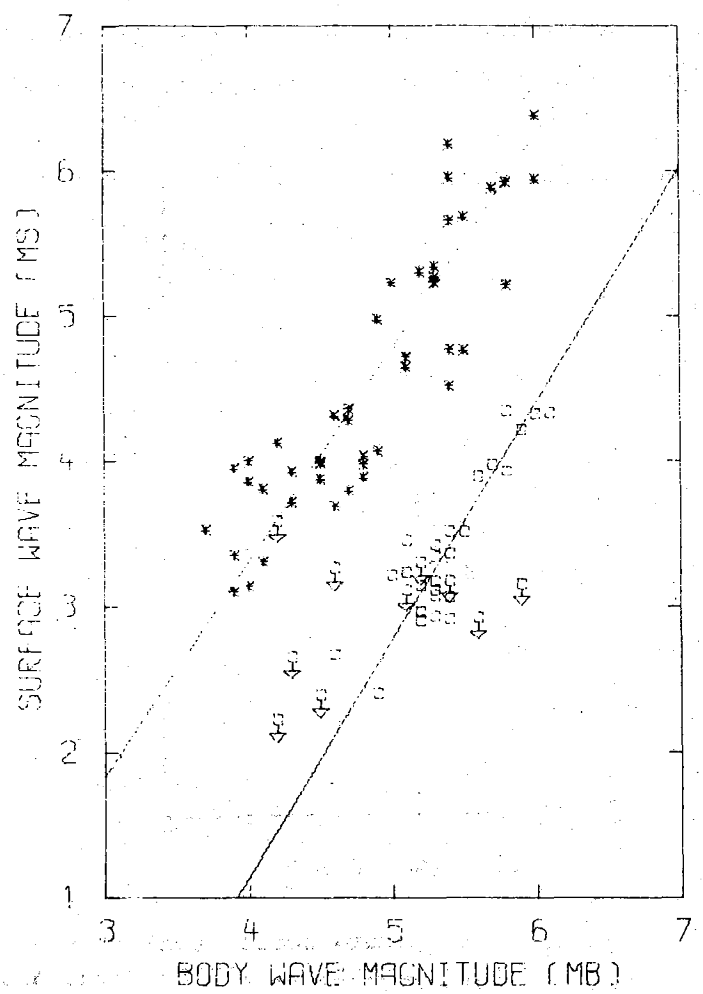

Figure J.1 NORSAR m_b versus M_s for events from Central Asia. Squares and asterisks denote presumed explosions and earthquakes, respectively. The straight lines are maximum likelihood linear regression lines. Arrows denote events for which no surface waves are found, the value being the upper boundary for M_s.

using a maximum likelihood method. A certain clustering of the presumed explosions make an estimation of identification threshold difficult, but from a brief look at the plot it seems to be difficult to get below m_b=5.0 with the requirement that the $m_b:M_s$ method be used as a positive identifier. Using lack of surface waves as negative evidence, identification may be possible down to at least m_b=4.5. It is obvious from Figure J.1 that the main limiting factor is the noise level on the long period records; it is seen that in the 10 cases where no Rayleigh waves are found from presumed nuclear explosions, the M_s level of the noise (measured on a filtered beam) ranges from 2.2 to 3.6, or more than one magnitude. This is consistent with the long term distribution of the long period noise presented in Figure J.2, where on year of data has been accumulated. Although large short term (= a few days)

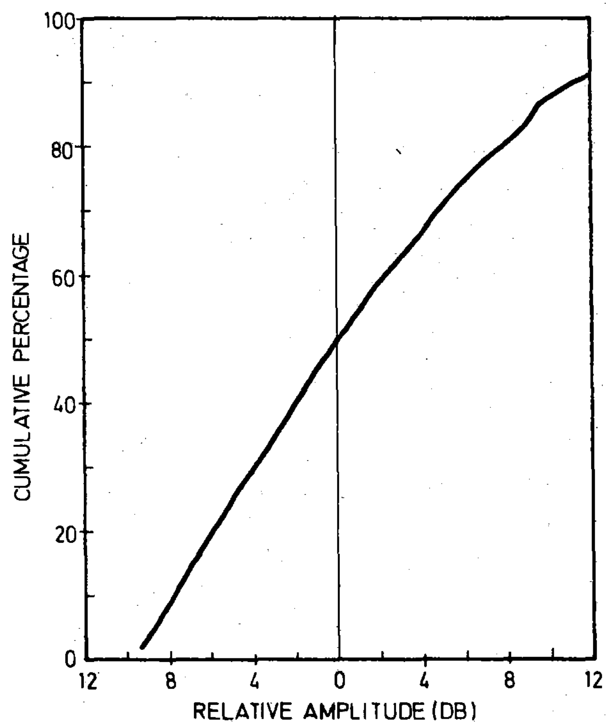

Figure J.2 The distribution of average noise level at the 22 long period vertical seismometers at NORSAR. The averaging is done over one year of data, from September 73 to August 74.

variations are observed, the dominating factor behind Figure J.2 is the yearly variation, with an average noise level during the winter months being almost 10 times that of the summer (which means that so far as NORSAR is concerned, the cheapest evasion technique is obtained by calling the meteorologist).

Figure J.3 shows the difference m_b-M_s plotted against m_b For earthquakes m_b-M_s is clearly correlated with m_b. Using the spectral theory of seismic sources (Aki 1972, Randall 1973), it is possible to estimate approximately how m_b-M_s changes with m_b. As described by Noponen (1974), it can be written

$$m_b - M_s = K + \log_{10}\{f_m F(f_m)\} - 1.36t^*f_m \qquad (1)$$

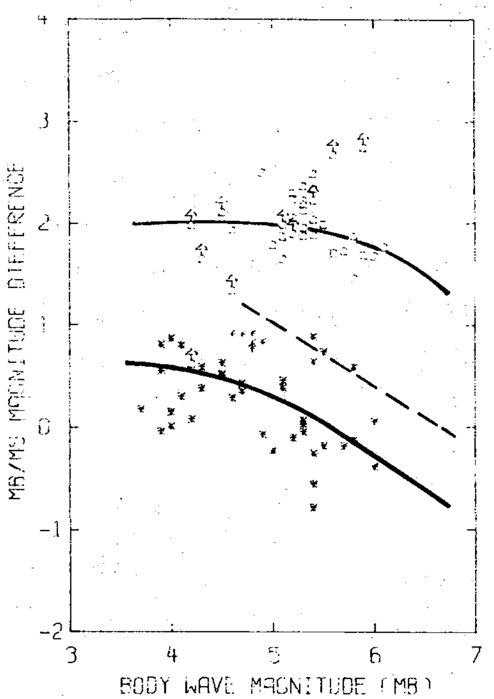

Figure J.3 m_b-M_s of events in Central Asia plotted against m_b. Squares and asterisks denote presumed explosions and earthquakes respectively. The continuous lines indicate predicted change of m_b-M_s as a function of m_b for both types of events. The broken line is the Gutenberg-Richter relationship.

K is a constant independent of m_b, f_m is the apparent frequency of P-wave used in computing m_b, it can be taken to correspond to the frequency of the spectral maximum of recorded P-wave. $F(f_m)$ is the ratio of the P-wave source spectral amplitude at frequency f_m to amplitude at zero frequency. t* is the ray path anelastic attenuation parameter. The values of equation (1) were evaluated for both earthquakes and explosions, using m_b-dependent P-wave source spectral shapes derived by Aki (1967) and by von Seggern and Blandford (1972), complemented with NORSAR observations on corner frequencies. f was estimated by synthesizing the recorded signal spectrum, taking into account the effects of signal absorption and instrument response. $F(f_m)$ could then be computed from the source spectral shape. t* was given the value 0.25. The values of K were estimated in that the levels of the computed m_b-M_s curves were fitted to the observations. Extrapolation of the curves to very low magnitudes suggests that although m_b-M_s decreases with magnitude, a residual difference of approx. 0.5 magnitude units remains between m_b and M_s, apparently caused by the different Rayleigh wave generation capacity of dilatational and shear sources. The slope of the derived m_b-M_s as a function of m_b agrees roughly with observations and at m_b>5 with the Gutenberg-Richter m_b:M_s relationship.

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K. MULTIPATHING AND GROUP VELOCITY

It has recently been demonstrated (Bungum and Capon, 1974) that the Rayleigh waves recorded at NORSAR have for most regions quite often taken a variety of paths depending on arrival time and wave period. This multipathing is caused by lateral variations in phase velocity, and is most serious for the shorter periods, typically below 30 seconds. An important implication of the multipathing observations is the effect on dispersion analysis. Traditionally, this has been done assuming that the energy has taken a great circle path. Our results indicate that this is an assumption which can be made only under very ideal circumstances. To demonstrate this, Fig. 1 shows the results of a dispersion analysis of an event recorded at NORSAR. The different wave packets are clearly discernable, and they all have quite different paths. The first part of the coda is a nicely dispersed wave train which turns out to have an azimuth of approach only $+1^{\circ}$ in difference from the true azimuth. Then at a group velocity between 3.35 and 3.15, the energy around 40 sec arrives from $+27^{\circ}$. The multipathing analysis at 20 sec period shows that the energy between 3.1 and 2.9 in group velocity is arriving with -15° in azimuth, between 2.9 and 2.7 the azimuth is $+11^{\circ}$, between 2.7 and 2.5 the azimuth is $+38^{\circ}$, and between 2.5 and 2.3 the azimuth is -34° relative to the true azimuth. The immediate effect of this is that most of the given group velocities are wrong, since the energy has travelled much longer than the great circle epicentral distance. This means that the observed dispersion may be more a function of the amount and type of multipathing than of the actual dispersive characteristics of the medium.

H. Bungum

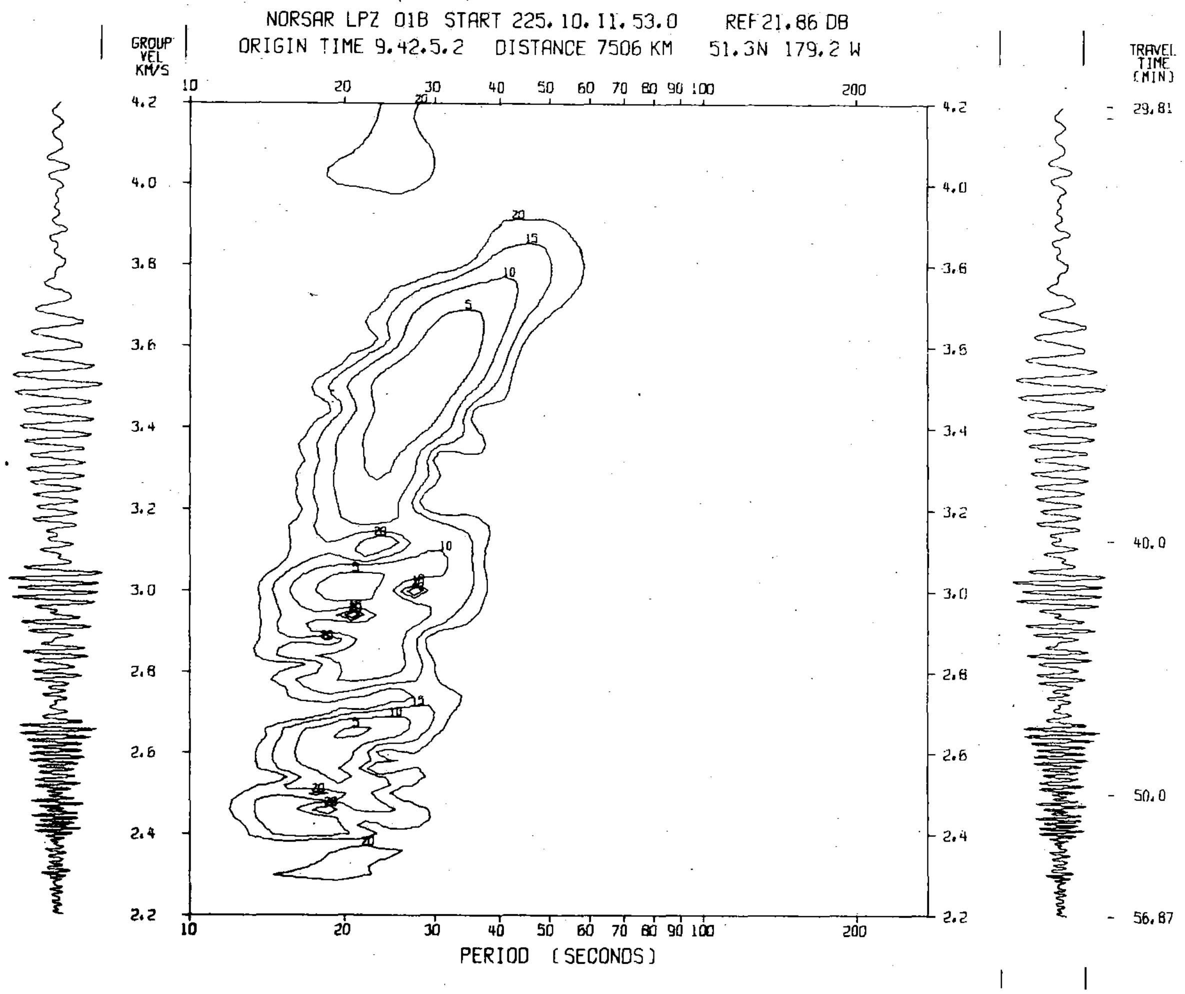

Fig. K.1 Power of NORSAR-recorded seismic surface waves as function of travel time and period, using a stack of Gaussian filters with constant relative bandwidth. The contours are in dB down from maximum. The event is an earthquake from Andreanof Islands (51.4N, 179.3W), origin time 12 Aug 1972 at 09.42.05.2 GMT, distance from NORSAR is 68°.

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L. FALSE ALARM AND NOISE STABILITY AT NORSAR

The large arrays LASA and NORSAR represent in general the most efficient tool available for detecting small seismic events. The basic operational principle of the array is beamforming; the array is regularly pointed towards a large number of prefixed points in all active seismic regions. The most commonly used detector is based on a continuous comparison between a certain parameter η and a preset detection threshold, η being the ratio between the linear array beam power measured in a short (STA) and a long time window (LTA).

The problem of declaring a signal detection represents a hypothesis test based on the test statistic η: declare a detection whenever η is equal to or exceeds a preset detection threshold (TH), i.e., choose hypothesis H_1. Otherwise, decide that H_1 is false, i.e., hypothesis H_0 is chosen. This binary decision model has two conditions: the false alarm or choosing H_1 when H_0 is true, and the missed detection or choosing H_0 when H_1 is true.

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

NORSAR event reporting performance and ways to improve the detectability of the array has been accomplished.

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

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

where bar indicates averaging and σ^2 is the variance of STA. S is a generalized measure of the spread in the η observations and is likely to be a sensitive indicator for phenomena of the type investigated here (Lacoss 1972).

Fig. L.1 shows the false alarm rate as function of S for different detection thresholds. The false alarm rate is defined as the sum of all detections reported to have an STA/LTA ratio larger than 8.5, 9.0, 9.5 and 10.0 dB respectively. "True" detections were defined as STA/LTA larger than 10.5 dB and henceforth removed from the sample population. Noteworthy, the noise stability-false alarm relationship was found to be independent of whether the noise field varies naturally or artificially by using bandpass filters. The results of Fig L.1 are used to find a mathematical relation between TH, S and false alarm rate, i.e.,

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

where FA is number of false alarms per hour. This relation makes it possible to fix the false alarm rate and let the threshold vary as function of noise stability. It can be shown that implementation of a floating threshold will imply an average gain in the number of reported events of a few per cent relative to a fixed threshold procedure. Other advantages are avoidance of system saturation during extremely noisy time periods, and a more economical use of the computer capacity. The floating threshold procedure is at present tested out in parallel with the present (fixed) on-line detection threshold.

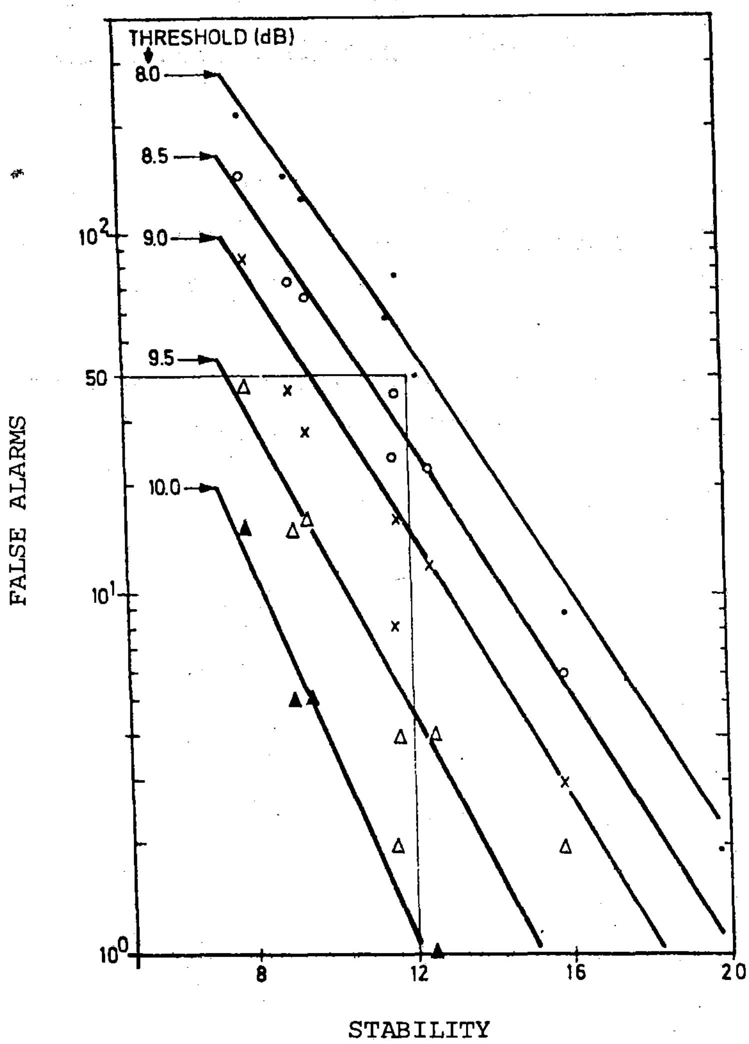

Fig. L.1 False alarm rate versus noise stability for different event detector threshold values. Three different noise situations were analyzed, each corresponding to 1 hour of NORSAR on-line processing. For further variations of the noise structure, 3 different bandpass filters were also used.

For further details on this topic we refer to a forthcoming paper authored by Steinert et al (1974).

O. Steinert
E.S. Husebye
H. Gjøystdal

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M. QUASI- AND SUPERCYCLICITY OF EARTHQUAKES AND TIME-MAGNITUDE GAPS IN EARTHQUAKE PREDICTION

The problem in earthquake prediction is to locate (with some probability) future earthquakes in time, space and magnitude, which are the three essential components of the earthquake prediction problem. Up to the present, most predictions (for large earthquakes) have been performed assuming that one or two of these components are constants (or varying in a chosen interval), the prediction being given for the remaining one. For example, Fedotov (1965), Mogi (1968, 1964), Sykes (1971) and Kelleher et al (1973) established and applied some criteria for the prediction in space when $M \geq 7$ or 7.8 and the time is restricted to 10-50 years.

The present analysis has been performed in the case when the space component is constant and prediction is attempted in time and magnitude (Purcaru, 1974a). Because all predictions are based on assumptions about the underlying causalities, expressed through regularities in the occurrence of the events, we established such regularities for the Vrancea-Carpathian seismic region. The region is characterized by a clustering of earthquakes of earthquakes in space ($\approx 1^{\circ} x 1^{\circ}$) with depths of 50-200 km. They occur rarely for $M \geq 5$-6 and are not in general followed by aftershock sequences. The strong earthquakes have M varying between 6 3/4 - 7 3/4. We compiled and carefully analyzed all information about strong-destructive shocks in this region for the years 1100-1974 for $M \geq 6\ 3/4$ ($I_{max} \geq 8^{\circ}$), where M is the G-R's magnitude The values of M have been calculated from macroseismic observations using the relation (Purcaru, 1974b):

$$M = -2.13 + 9.85 \log I_{max},$$

for

$5 \leq M \leq 7\ 3/4$

H=50 - 180 km.

After many trials we found that the occurrence of Vrancea-Carpathian earthquakes in the above time period (from 1300-1450 we have no data) is characterized by a regularity expressed through a clear alternation of seismic (active) and aseismic (inactive) periods corresponding to three time-bands $B_{ST}^{(1)}$, $B_{ST}^{(2)}$ and $B_{ST}^{(3)}$ for the former ones (see Fig.M.1). These three time-bands represent the first and strongest regularity in the occurrence of these shocks. The periods are covering the years 0-10 (period P_1), 30-40 (period P_2) and 70-90 (period P_3) of every century. In every P_i (i=1,2,3) we established another regularity expressed by the fact that the shocks occur quasicyclic from about 100 to 100 year. These intervals called quasicycles have the following lengths: $\bar{T}(P_1)=96 \pm 7$ yr, $\bar{T}(P_2)=100 \pm 15$ yr and $\bar{T}(P_3)=104 \pm 16$ yr. Furthermore in the occurrence of shocks with $M \simeq 7\ 1/4 - 7\ 3/4$ it has been observed another regularity: these shocks occur in every active period with recurrence time of about 300 years. These intervals have been called supercycles, which, together with the established quasicycles were used to estimate time-magnitude gaps defined as the likely positions in time and size for future destructive earthquakes. Although the occurrence of the shocks in every P_i is characterized by the quasi- and supercycles, the occurrence of events in these seismic periods are not strictly periodic. If a shock does occur in such a prediction position, we have a stop-gap in time and magnitude correspondingly. Also the time influence of the size of a shock on the next one was established and used in the attempted prediction. Thus, following an algorithm of extrapolation, the final

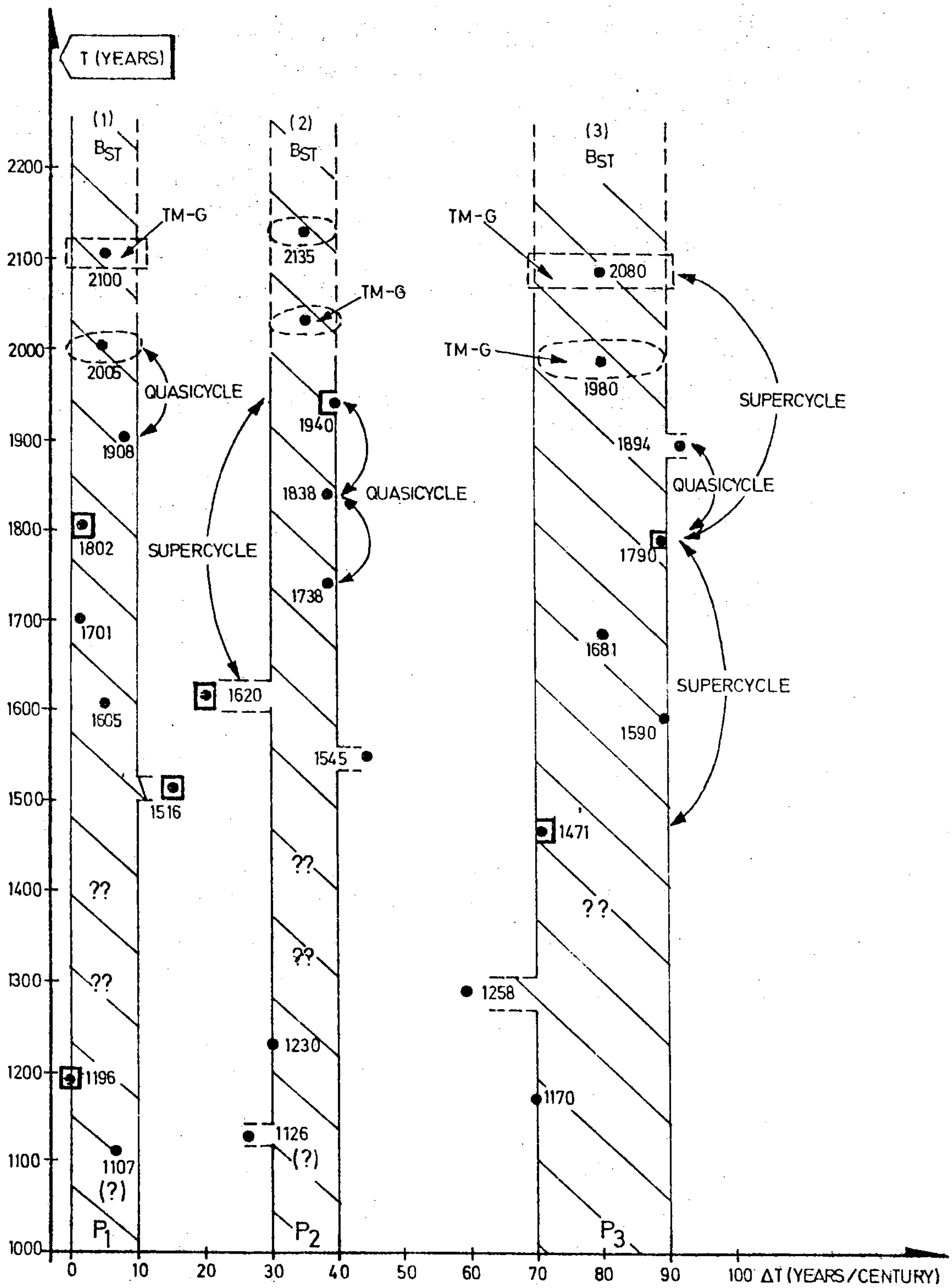

Fig. M.1 Time-magnitude pattern of Vrancea-Carpathian strong intermediate earthquakes. (text continued next page)

Fig. M.1 (Text continued)

ΔT: time period of a century, in year/century

$B_{ST}^{(1)}$, $B_{ST}^{(2)}$, $B_{ST}^{(3)}$: seismic time bands

P_1, P_2, P_3: time periods corresponding to $B_{ST}^{(1)}$, $B_{ST}^{(2)}$, $B_{ST}^{(3)}$, respectively, in every century

• and |•|: time distribution of earthquakes with (1) M=6 3/4-7 and (2) 7 1/4 $\leq$ M $\leq$ 7 3/4, respectively.

??: no information

The attached number represents the year of occurrence of earthquakes.

TM-G: time-magnitude gaps

(•) and [•] : TM-G, corresponding to (1) and (2), respectively, for prediction.

results appear to indicate the occurrence of a shock with $M \approx 6\ 3/4 - 7$ in 1980 ± 13 years. Later earthquakes were predicted in 2005, in 2030-40 ($M \approx 6\ 3/4 - 7$) and one with nearly maximum magnitude ($M = 7\ 1/2 - 7\ 3/4$) in 2070-90.

G. Purcaru

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N. A NEW QUANTITATIVE MEASUREMENT OF SEISMICITY

The seismicity of various regions and the methods for estimating this has been the subject of intensive studies by numerous seismologists. The magnitude-frequency relation of Gutenberg-Richter (1944) which is accepted as the most generally valid may be expressed as follows:

$$\log n(S_Q, T, M) = \alpha_0(S_Q, T) - bM$$

where n is the number of earthquakes with magnitude $\geq M$ in the seismic region Q with area S_Q in a time period of T years.

Normalizing n per unit of space and time gives:

$$\log N(M) = \log A_k - b(M - M_k)$$

where M_k is a threshold magnitude. The parameter A_k has been used as a quantitative measure of seismicity when $b \simeq$ constant. In reality b is, however, not constant and may vary between 0.5 and 1.5. It thus follows that neither A_k nor b can be used separately to measure the seismicity if b is different in two regions.

In the new method, a world mean standard magnitude-frequency relation with b standard = 1 has been established both for the case when surface wave magnitude or body wave magnitude are used. Correspondingly the mean standard frequency activity A_S when M is greater than μ is given by

$$A_S = 10^{-0.41} \cdot 10^{-(M-\mu)}$$

The new quantitative measure of seismicity called 'the relative level of seismicity' is given by

$$L_k^{RS} = \frac{A_k}{A_S}$$

when $M_k \geq \mu$.

The application of the method is demonstrated by Purcaru (1974).

G. Purcaru

REFERENCE

Purcaru, G. (1974): A new quantitative measure of seismicity and some related aspects, in a special issue of "International Symposium on Seismology and Physics of Solids of the Earth's Interior", Jena (DDR), 1-6 April 1974, in press.

O. DETECTION PROCESSOR OPERATION

Apart from an 81 hour break in the recording, due to breakdown of the Special Processing System (see below), the Detection Processor has been run with the purpose of having minimal system down time in this period. The Detection Processor has thus been up 97% of the time, as compared to 98.3% in the last reporting period. No significant changes have been made to the DP software in this period.

Data Recording and DP Down Time

Figure O.1 and the accompanying table O.1 show the daily total DP down time in hours, for the days between 1 January and 30 June, inclusive.

The monthly recording times and percentages up are given in Table O.2, while Tables O.3 and O.4 compile statistical data on the overall use of the A and B computers, respectively. As is clearly visible from Figure O.1, the overshadowing event in this period was the breakdown of the Special Processing System (SPS), which was due to a malfunctioning hardware component. Around 81 hours elapsed before the error was located and repaired, causing a corresponding time gap in the recorded data.

Additionally, around 50 hours of down time is spread evenly in the period, with a little increase in June. This last effect is explained by the frequent summer thunder storms, causing power breaks and jumps. Table O.1 lists the day number, start and stop time for each break, together with a short comment. The 100 breaks in the period can be grouped:

Tape drive problems	15
Power breaks/jumps and related stops	13

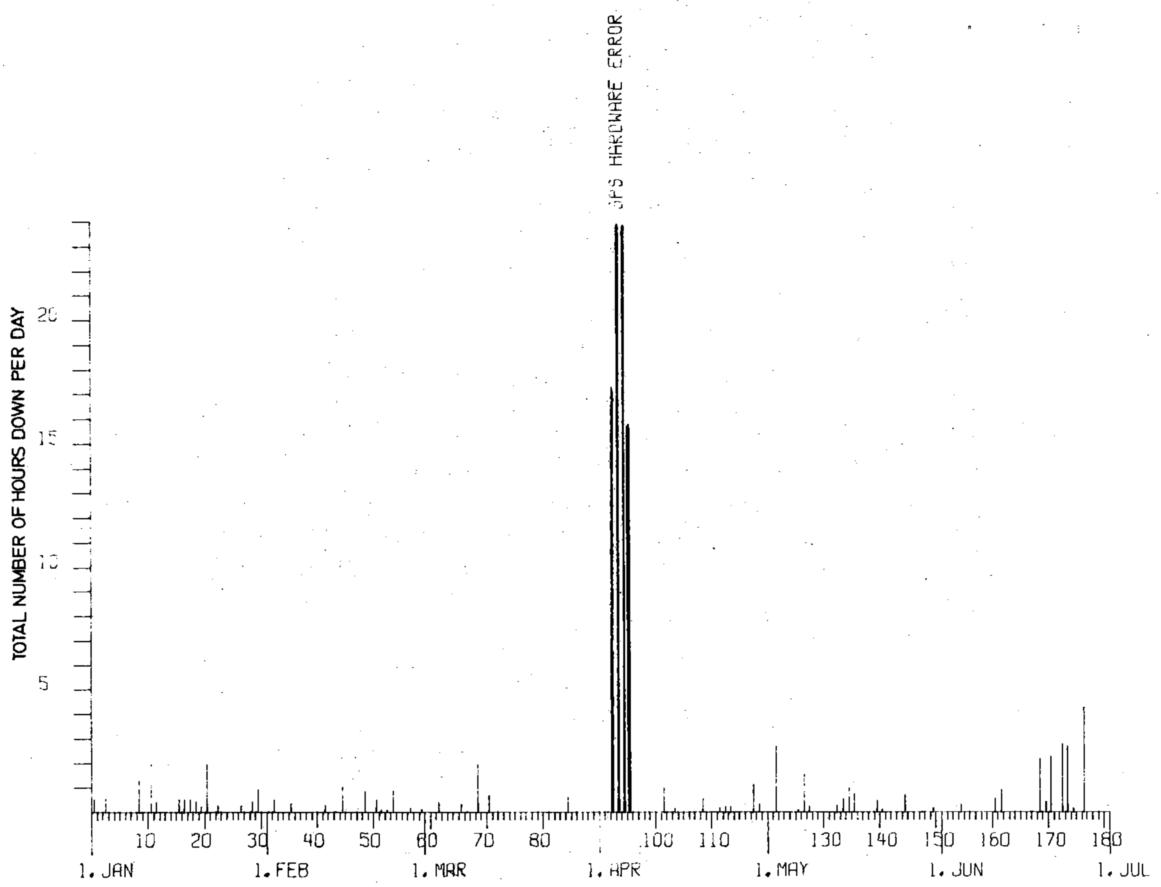

Fig. O.1 Daily Detection Processor down time Jan-June 1974.

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS..........
1	2	20	2	30	WRONG TIME ON DP MSG
1	7	20	7	25	WRONG TIME ON DP MSG
1	17	49	18	7	TOD ADJUSTMENT
3	8	27	9	3	TEST 160 TAPE DRIVES
9	10	50	12	7	POWER BREAK
11	8	6	8	52	CE WORK
11	11	12	12	1	CPU ROS/DATA & CTRL ON
11	15	45	16	8	CPU ROS/DATA & CTRL ON
12	13	47	13	58	BAD PRINTER A TO B
12	16	27	16	42	POWER BREAK
16	7	15	7	22	B TO A
16	9	51	10	17	UNKNOWN
17	3	36	4	10	CPU ERROR
18	3	22	3	34	TAPE SPOOLING
18	19	8	19	29	CPU ROS/DATA & CTRL ON
19	1	1	1	29	UNKNOWN
20	12	26	12	40	SHARED DISK DOWN
21	7	41	9	34	SHARED DISK DOWN
21	12	32	12	37	RESTORE ECC LIGHTS
23	13	10	13	16	PROGRAM CHANGE
23	13	35	13	47	SWITCH CARD READERS
27	12	54	13	12	TAPE DRIVE TROUBLE(161)
29	14	40	15	8	SPS INTER NOT RECEIVED
30	19	55	20	51	CPU ROS DATA/CTRL ATOB
32	14	0	14	4	B TO A
33	12	32	13	3	TAPES SPOOLING A TO B
36	9	39	9	44	B TO A
36	15	11	15	29	TAPES SPOOLING
42	11	55	12	13	CPU ROS DATA/CTRL ON
44	11	51	11	55	PROG CHANGES
45	16	7	16	26	CPU ROS DATA/CTRL ON
45	21	2	21	46	CPU ROS DATA/CTRL ON
49	1	0	1	13	CPU ROS DATA/CTRL ON
49	10	9	10	31	POWER JUMP
49	17	20	17	25	SELECT LIGHT ON 161
49	17	30	17	36	TAPES NOT ACCEPTED
49	17	39	17	45	TAPES NOT ACCEPTED
51	12	30	12	36	CHANGE ROS-TAPE A TO B
51	14	30	14	35	B TO A
51	17	50	18	11	CPU ROS DATA/CTRL ON
52	13	0	13	7	WRONG TIME ON DP MSGS
53	23	54	24	0	I/O ERROR,CHN CNTRL CHK
54	0	0	0	19	I/O ERROR,CHN CNTRL CHK
54	15	56	16	31	UNKNOWN
57	2	0	2	10	CHNL 2 BLOCKED BY EP
59	18	13	18	19	PROG CHANGE TEST
59	10	34	10	37	PROG CHANGE
62	14	31	14	56	EX & EARLY LIGHT ON
66	21	54	22	14	TAPE ERRORS ON 253
67	10	55	10	59	PROG CHANGE(160S UP)
69	10	54	12	21	SHARED DISK NOT READY
69	19	51	20	23	1052 BAD A TO B
71	12	31	13	12	B TO A
85	10	7	10	44	POWER JUMP
92	14	28	14	32	CHANGE TAPE DRIVES
93	6	39	24	0	SPS HARDWARE ERROR

TABLE O.1

(Sheet 1 of 2)

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS...........
94	0	0	24	0	SPS HARDWARE ERROR
95	0	0	24	0	SPS HARDWARE ERROR
96	0	0	15	52	SPS HARDWARE ERROR
102	20	53	21	29	CPU STOP MPX & LATE ON
102	23	6	23	30	CPU STOP MPX & LATE ON
104	6	0	6	11	MPX & LATE ON A TO B
109	10	14	10	24	B TO A
109	22	45	23	10	SELECT LIGHT ON 164
112	10	56	11	7	MPX & LATE LIGHTS ON
113	19	50	20	4	MPX & LATE LIGHTS ON
114	17	35	17	49	SELECT LIGHT ON 162
118	3	6	4	3	POWER JUMP A TO B
118	9	34	9	45	UNKNOWN
119	10	41	11	1	UNKNOWN
122	3	10	4	29	POWER BREAK
122	4	34	5	13	POWER JUMP
122	9	23	10	8	SPS FRAME 1 CB OFF
126	14	26	14	32	PROG CHANGE TEST BTOA
127	6	59	8	32	DISK TROUBLE
128	22	11	22	26	POWER OFF/ON
133	7	6	7	10	SET UP NEW VERSION
133	7	16	7	30	PROG CHECK
134	3	47	4	6	PROG CHK OLD VERS. UP
134	10	3	10	6	PROG CHANGE
134	12	35	12	49	PROG CHECK
135	19	19	20	19	MPX & LATE LIGHTS ON
136	18	4	18	50	MPX & LATE LIGHTS ON
140	17	23	17	53	WRONG TIME ON DP MSGS
141	13	45	13	54	MPX & LATE LIGHTS ON
145	12	53	13	19	TAPE SPOOLING (274)
145	14	46	15	3	TAPE SPOOLING (274)
148	9	0	9	5	PROG CHANGE
150	4	4	4	14	PROG CHANGE TEST
155	21	47	22	8	MPX CHANNEL TIED UP
161	1	33	2	8	PLOT TAPE NOT COMPAT.
162	15	35	16	31	UNKNOWN
169	3	59	4	54	SPS RED LIGHT FRAME 1
169	5	7	5	23	SPS RED LIGHT FRAME 1
169	5	28	6	30	SPS RED LIGHT FRAME 1
170	0	14	0	42	SPS RED LIGHT FRAME 1
171	11	3	11	33	POWER FAILURE
171	11	33	13	20	NO SPS INTER RECEIVED
173	1	23	1	35	SPS AIR CONDITION
173	14	14	16	52	POWER FAILURE
174	3	45	6	27	UNKNOWN
175	0	38	0	48	AIR CONDITION STOP
177	15	35	19	18	THUNDER A DOWN
177	19	50	20	25	POWER UP ON A

TABLE O.1

(Sheet 2 of 2)

TABLE O.2

DP and EP Computer Usage, 1 January - 30 June 1974

Month	DP Uptime (Hrs)	DP Uptime (%)	EP Uptime (Hrs)	EP Uptime (%)	No. of DP Error Stops	DP MTBF (Days)
Jan	735	98.8	248.5	33.4	24	1.3
Feb	666.5	99.2	206	30.7	22	1.3
Mar	740.5	99.5	207	27.8	7	4.4
Apr	635.5	88.2	163	22.6	13	2.0
May	734.5	98.8	242	32.5	19	1.6
Jun	703.5	97.7	216	30.0	15	2.0
Total	4216	97.0	1283	29.5	100	1.7

TABLE O.3

A-Computer Usage (Hrs), 1 Jan - 30 June 1974.

Month	DP	EP	Job Shop	Data Ret. Copy	Array Moni-toring	DP Test	C.E. Maint.	Power Break	Machine Failure	SPS Failure	Plot in Fl	Hands On
Jan	619	55	46	19	7	1.3	4	2	3.5		34	
Feb	582	32	19		6	0.5	4.3	0.5	4		21	
Mar	700	7	14		1.5		9.5	0.5	9		17	
Apr	444	45	50		6			1	2	81	75	6
May	603	36	27		11	1.5	0.2	3	4.5		35	2
Jun	703.5							10	3		23	
Total	3652	175	156	19	31	3	18	17	26	81	205	8

TABLE O.4

B-Computer Usage (Hrs), 1 Jan - 30 June 1974.

Month	DP	EP	Job Shop	Data Ret. Copy	Array Moni-toring	DP Test	C.E. Maint.	Power Break	Machine Failure	Plot in Fl	Hands On
Jan	116	193.5	297	117	16.5		2.3	2		181	
Feb	84.5	174	318	70.5	30.5		3	0.5		206	
Mar	40.5	200	338	97	37.5	2.3	18.5	0.5		211	
Apr	191.5	118	174	61	16		0.5	1	0.5	105	11
May	131.5	206	283	107.5	33		2	3		197	
Jun		216	408	44	45		1	10		180	
Total	564	1108	1818	497	179	2	27	17	0.5	1080	11

SPS problems	8
Shared disk down	3
Other hardware problems	36
CE maintenance	1
Software problems	13
TOD (Time-of-day) adjustment & related problems	5
Unknown	7

Included under the different headings are the stops caused by re-starting DP on the A computer after error recovery.

The "Shared disk down" category contains the cases when the operator stopped DP because no detections were written to the disk pack shared between DP and EP. Due to a software modification, DP now warns the operator, by ringing a bell, every time it has something that should have been written on the disk pack declared down. The "Software problems" category also contains the cases of restarts with program modifications.

The total down time for the period was 131 hours 22 minutes. The overall mean time between failures was 1.7 days, compared to 1.6 days for the last reporting period.

DP Algorithms and Parameters

No major changes have been introduced in DP algorithms or parameters this period. In addition to the modification mentioned above, coding has been changed to prevent printing of redundant output from DP, thus reducing the total output volume in order to save paper.

Also, preparatory changes have been made to eventually overlay the message task. This is done to gain core space for the implementation of a future Network Control

Program. However, to make DP work properly with the message task as an overlay, modifications must be done in the DOS Supervisor. These modifications are presently being investigated.

D. Rieber-Mohn

P. EVENT PROCESSOR OPERATION

General Considerations

The Event Processor programs are still vulnerable to improper/incorrect input data from the files on the Shared Disk Pack. However, a battery of off-line utility programs has been developed. These programs makes it easy to check file content, move pointers, and to change incorrect entries in these files.

Computer Utilization

During this period the Event Processor (EP) was up and running 29.5% of the time, compared to 41.1% in the last reporting period. This significant decrease in processing time is caused by various factors, such as a decrease in the total number of processed detections, fewer EP breakdowns with reprocessing of already processed data, and implementation of an SNR pre-processing threshold with diurnal variation (see below).

EP Operational Problems

The Shared Disk Pack, which is the communication link between DP and EP, was declared to be down from DP on 19 January, caused by the disk pack being in the "rest ready" status for a short while. This went unnoticed by the operator. Since EP got no new detections to process, it was idle after processing the detection comprising the lag in time between DP and EP. On 20 January the Shared Pack was declared up by the operator. The missing interval was processed by off-line EP, using the Detection Log tape as input. To prevent such an event to occur once more, some of the DP routines have been modified to alert the operator repeatedly when the Shared Pack is declared down (described elsewhere).

On 1 February the EP terminated each time it was executing the Detection Bulletin File Generation Package in Job Step 3. Investigation of the dumps showed that during the "publish" function, both partitions of the Detection Bulletin File had the same date. This caused a situation not accounted for in the algorithms, and thereby a following termination. On 3 February the deadlock was broken by performing a "release" function from the 1052 console in Job Step 4. To secure that one partition always was picked to be published, even if the two dates were identical, a small modification was implemented in the corresponding algorithm.

On 24 June the Time-of-Day (TOD) unit stopped because of a power break, and was afterwards started with a completely erroneous time. It ran for a short time with this incorrect time before it was stopped and adjusted. However, some detections had already been written to the Signal Arrival Files on the Shared Pack with wrong start and stop times. Also, entries had been written to the Shared Pack Time/Tape File, which contained erroneous start and stop times for the tapes. The erroneous times were propagated to the Detection File, and a loop occurred in the Detection Bulletin File Generation Package when one of these times were read from the Detection File. Also, the wrong times in the Time/Tape File entries caused many detections to be processed with EP-code=3 ("No HR-tapes available"). Various utility programs were used to move pointers past bad detections in the Signal Arrival Files, and to correct the bad times in the Time/Tape File entries.

EP Parameters and Algorithms

The following changes were made to the Event Processor system in this period:

On 28 February an improved version of the procedure for local events and glitches was implemented. DP performs six different tests on detections to check if they might be local events (explosions) or glitches. The results of these tests are sent to EP along with the detection via the Shared Pack Signal Arrival Files. On the basis of these test results, EP classifies the event as local, glitch or processable. The improved procedure accepts more events for processing (not local or glitch) than was allowed in the old version.

At the same time the read-in logic of incoherent detections from the Shared Disk Pack file was simplified in such a way that no wait for a duplicate arrival is taking place, since duplicate arrivals cannot take place under incoherent beamforming. Also the ringing of the alarm bell was removed from the "ready-for-operator-input" message as this was considered superfluous.

The Event Family Grouping procedure, which has been implemented as a separate overlay in the EP monitor, has never been working properly. Its only function has been to read a phase from the Phase/Hypothesis table. On 8 April the Event Family Grouping phase was removed, and corresponding modifications performed in the EPCON part of the monitor. This simplifies EP logic considerably, and reduces the monitor overhead time for each event.

At the same time implementation of a statistical sign-bit semblance test in the Beampacking and Array Beamforming package was performed. The result of the test is normalized and saved as an intermediate result in the Short Period Variable File for the event on disk, to be printed out later by the Summary Report Package in Job Step 3.

Also, a small change in the tape management routine now secures that the volume label of an input tape conforms to ISRSPS standards.

EP Performance Statistics

A summary of the analyst decisions for each of the detections processed by EP is given in Table P1. The statistics are not significantly different from previous reporting periods, although somewhat fewer events are reported, which can be attributed to variations in seismicity. A somewhat more effective computer utilization should be expected after the introduction of a diurnal variation in pre-processing threshold, leading to a constant false alarm rate throughout the day (but

TABLE P1

Analyst decisions for detections processed by EP during the time period January-June 1974.

Analyst Classifications	Number of Processings	Percentage
Accepted as events	3298	47.0
Rejected as being		
- Poor SNR or noise	1412	20.1
- Local events	1103	15.7
- Double processings	671	9.5
- Communications errors	539	7.7
Sum processed	7023	100.0

not necessarily fewer noise detections). A more effective screening of local events has also been introduced (28 Feb), and the fact that there are equally many local events processed must therefore be due to the occurrence of a larger number of such events. Finally, it should be noted that one third of the detections caused by communication errors occurred during one week in June with high activity of thunder and lightning.

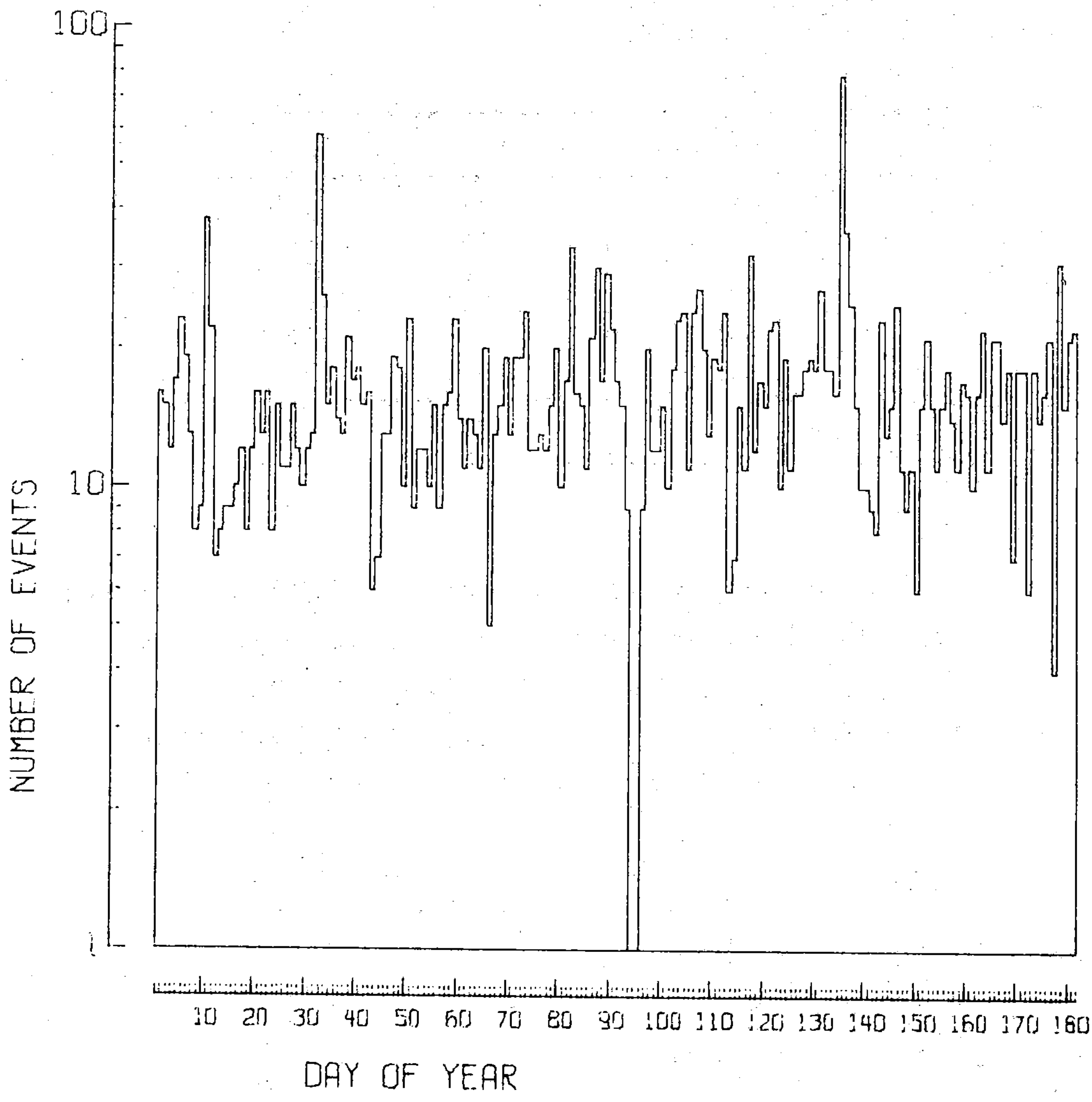

Fig. P.1 Number of reported events as a function of day of year for Jan-June 1974.

TABLE P2

Number of teleseismic and core phase events reported during the time period January-June 1974.

Month	Teleseismic	Core	Sum
Jan	308	111	419
Feb	322	139	461
Mar	361	155	516
Apr	355	102	457
May	451	121	572
Jun	364	118	482
Sum	2161	746	2907

The number of reported events on a monthly basis is given in Table P2, and the distribution on a daily basis is given in Figure P1. It should be noted that the last 40 days were relatively quiet, especially taking into account that the noise level was quite low.

D. Rieber-Mohn
H. Bungum

Q. PROGRAMMING ACTIVITY

The programming group, consisting of 5 persons, has in this period been working in the following fields of activity:

- development of new programs
- maintenance and improvement of existing program systems
- routine processing of utility and application programs
- consultation support
- use of the ARPA network and related studies

The maintenance of program systems and the use and study of the ARPA network is described separately, in their respective chapters.

Development of New Programs

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

- A program that processes output from the Channel Evaluation Program (CHANEV) and gives mean values and standard deviations, as well as tables of parameter values.
- A program utilizing 4 different test statistics on subarray beam data from the Event tape (i.e. already processed events) to check the validity of using the tests in signal-noise classification and rank them accordingly, together with subroutines for filtering, enveloping, etc.
- Subroutines that contain updated Beam Location Tables for NORSAR and LASA, respectively, and which return relevant data for a beam location, when inputting the beam number and partition.

- A subroutine that reads the short period seismometer values and the relevant data flags from the LASA High Rate tape.
- A subroutine that facilitates backward reading of a magnetic tape.
- A subroutine that reads the recording tape of the Kongsberg High-gain, Broadband, Long Period Seismograph station. A corresponding plot routine is being prepared.
- Additionally, programs received from other institutions have been modified to fit NORSAR needs. A program (GROUVE) that employs a multiple filtering technique in order to obtain a pattern of amplitude versus group velocity and period, can now use the Low rate tape as input. The International Mathematical and Statistical Libraries program package was received in April. An accompanying Library Utility was modified to allow input of multiple tape volumes.

Routine Processing

The processing routinely undertaken consists of supervising and running of the following programs:

- Maintenance of the NORSAR Tape Library directory, using the Tape Library Program.
- Running discrimination test programs on data from suspicious events, and compilation of explosion data.
- Running and controlling the Data Retention program, in order to select and stack on other tapes data from High Rate tapes at the end of the retention period.
- Running a program that performs retention of the Detection Log tapes, selectively picking records from these tapes and stacking them on other tapes.

- In addition, various programs have been run infrequently, upon request from scientists, visitors and other institutions.

Consultation Support

A small, but important part of the work load of the programming staff consists of advising and helping others in matters related to programming. A thorough revision of the "Computer Assistance for Visitors Guidelines" was made, together with the Administrative Secretary, bringing the guidelines related to programming up to date.

In addition, debugging, re-programming and programming guidance has been performed by the programming staff.

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R. Rud
J. Fyen
S. Skribeland
V. Berteussen

R. THE NORSAR ARPANET CONNECTION

The ARPANET Terminal Interface Processor (TIP) and associated equipment, including communications lines to London and Alexandria (Seismic Data Analysis Center (SDAC)) have showed stable performance, with only sporadic and short failures. A tendency towards better transmission of seismic data on the shared link between NORSAR and SDAC has been observed, although the transmission appears to be not quite up to pre-TIP standard. Throughout this period the access to the ARPANET given by the TIP has been used actively, either from local terminals (2) or from terminals in neighbor institutions (2).

Since our trial account on the PDP-10 computer at the University of Southern California Information Science Institute was brought to an end, we have been registered as a user only on the PDP-10 (TENEX) machine at the Stanford Research Institute Augmentation Research Center (SRI-ARC). With the establishment of OFFICE-1 for network users willing to pay for the resources offered (NLS, etc.), we remained at SRI-ARC. Some use has been made of the NLS facility there, for document generation and text file manipulation. Also, this has been our "network address", from where we could send and receive messages, using the SNDMSG facility. However, to use compilers for computational high level languages, we have had to use the facilities offered at "free" Hosts in the network (like the Host at the Stanford University AI project). Source files for programs to be used have been stored at SRI-ARC and transferred (with the File Transfer Protocol process) to the Server in question for compilation and execution.

Since the beginning of May we have regularly delivered our seismic bulletin to the U.S. Geodetic Survey (USGS) through the ARPANET, thus speeding up the delivery and at the same time presenting the data in a form more directly usable by the USGS. The data are delivered to the message file of the directory established for USGS at the OFFICE-1 Host computer in the network, with the use of the SNDMSG facility at SRI-ARC.

Two terminals (Tektronix 4023 and Data Dynamics 390) were connected remotely to the TIP from Sandefjord, Norway, some 100 miles from Kjeller, during the course of the NATO Advanced Study Institute held there on "Exploitation of Seismograph Networks", between 23 April and 3 May. Several demonstrations were held, such as retrieval of seismic data from the CCA Datacomputer, remote batch processing and interactive processing. A small scenario had been compiled and gave interested participants of the seminar an opportunity of trying out some of the "free" resources in the ARPANET.

An additional terminal (Tektronix 4010-1 display terminal) was attached to the TIP at the end of May, giving NORSAR an additional ARPANET access. The new terminal facilitates the scanning of directories and files. In addition, it has a graphics capability, which may be useful in the future, and a hard copy unit attached (Tektronix 4610).

Source listings of the Network Control Program (NCP) implemented on the IBM 360/44 at the Seismic Data Analysis Center (SDAC) have been studied extensively. With the arrival of the necessary Host-Imp interface unit (on order), we eventually plan to implement this NCP on our B-machine, opening up another access to the ARPANET as a User Host. Also, valuable experience is obtained for the task of implementing an NCP for the on-line transmission of seismic data at SDAC.

Presently, as seen from the above-mentioned facts, our use of ARPANET resources are rather limited. With the present trend in ARPANET, where the number of "free" resources is reduced to zero, our plans for using the ARPANET to do interactive computing (which could be very useful for the analysts), seem to dwindle. If we also should lose our account at SRI-ARC, our ARPANET access will not be of very much use to us at the present time.

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P. Tveitane

S. NORSAR DATA PROCESSING CENTER (NDPC) OPERATION

Data Center

For facilities, refer to previous semiannual report (Scientific Report No. 4-73/74). No substantial changes in the facilities or equipment occurred in the report period. An initiative was taken to have the previously hired sections of the semi-permanent office building transferred to the project.

As usual some personnel changes occurred in the operator group. Two operators left in the period, and new personnel were hired. Two others have given notice of leaving during the summer.

Maintenance of equipment continued as before, except that project personnel accomplished repair work on some of the special equipment (display units). Equipment in general performed satisfactorily, although various malfunctions occurred, in particular in peripheral equipment. Because of equipment redundancy, there has usually been no problem in keeping the system going. However, a tendency towards more frequent malfunctions is observed, the probable cause of which is equipment aging.

One serious stop occurred 3-6 April, due to a malfunction in the Special Processing System (SPS). As there is no back-up for this machine, the whole system stopped. Because of the complexity of this machine, it took about 3 days to get it running again. (Two faults were eventually located.)

Another phenomenon causing some concern is the difficulty encountered when starting the system after a power failure.

For a review of computer usage, refer to Chapters O and P.

Communications

In spring and summer communication outages invariably increase compared to the winter months. Average subarray communication outage, typically as low as 1-2% during winter, may increase to 10% or even more during summer. A summary of communication outages in this period is given in Table S.1. As before subarrays are treated separately, although outage may concern groups of several subarrays, e.g. 03C, 04C and 05C down continuously for several days in June, caused by a lightning stroke in a cable. Outage figures are based on the automatic on-line print-outs.

P. Tveitane

TABLE S.1

Communications, degraded/outages.

Sub-arrays	JAN		FEB		MAR		APR		MAY		JUN		Total Hours degr./down		Per Cent degr./down	
	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200
01A	10.0	11.5	2.0	7.0	1.5	-	1.0	-	2.5	-	2.5	1.0	19.5	19.5	0.5	0.5
01B	10.0	11.5	2.0	7.0	2.0	-	1.0	-	2.5	-	2.0	2.0	19.5	20.5	0.5	0.5
02B	8.5	10.0	1.0	26.5	1.5	-	1.0	-	2.5	-	2.5	2.0	17.0	38.5	0.4	0.9
03B	8.5	9.5	1.0	7.0	1.0	-	1.0	-	2.5	-	2.5	1.5	16.5	18.0	0.4	0.4
04B	7.5	10.0	0.5	7.0	2.0	-	1.0	5.0	3.0	2.0	3.0	68.5	17.0	92.4	0.4	2.2
05B	4.0	2.0	4.0	7.0	3.5	6.5	5.0	3.5	4.0	0.5	41.5	30.0	62.0	49.5	1.5	1.2
06B	74.0	2.5	6.5	4.5	5.0	95.5	11.5	5.5	4.5	14.0	2.0	46.5	103.5	168.5	2.5	4.0
07B	3.0	1.0	1.0	5.5	3.5	12.0	2.5	4.5	4.0	2.0	5.0	101.5	19.0	126.5	0.5	3.0
01C	2.0	3.0	2.0	9.5	2.0	12.0	4.5	8.5	3.5	1.0	1.5	261.0	35.0	295.0	0.8	7.0
02C	8.0	10.5	2.0	7.5	3.5	2.5	2.0	-	3.0	-	2.5	27.0	21.0	47.5	0.5	1.1
03C	6.0	12.5	1.5	7.5	1.0	6.0	2.0	3.5	2.0	-	-	274.0	13.5	302.5	0.3	7.2
04C	7.0	10.5	1.0	7.0	4.0	2.5	1.0	-	2.5	-	1.5	274.0	17.0	294.0	0.4	7.0
05C	7.0	38.5	2.0	56.0	2.0	1.5	1.0	-	3.5	1.0	1.5	274.0	17.0	371.0	0.4	8.8
06C	8.5	49.0	2.5	61.5	1.0	-	1.0	0.5	2.5	13.0	2.5	6.5	18.0	130.5	0.4	3.1
07C	-	-	-	11.5	1.0	15.0	-	-	1.5	5.0	43.0	10.5	45.5	42.0	1.1	1.0
08C	-	-	1.0	10.5	0.5	2.0	1.0	-	2.0	8.0	1.0	1.5	5.5	22.0	0.1	0.5
09C	2.5	2.0	0.5	99.0	444.5	188.5	4.5	3.0	317.0	3.0	5.0	46.0	774.0	341.5	18.4	8.1
10C	4.0	3.0	1.0	37.5	3.0	12.0	2.5	3.0	4.5	-	6.0	48.0	21.0	103.5	0.5	2.5
11C	3.5	1.5	1.5	8.5	1.0	12.5	2.5	3.5	2.5	3.5	3.5	29.0	14.5	58.5	0.3	1.4
12C	2.5	2.0	-	8.5	1.5	11.5	2.5	4.0	3.5	0.5	5.0	29.0	15.0	55.5	0.4	1.3
13C	3.5	3.5	1.0	10.5	2.0	16.0	2.5	4.0	3.5	1.0	5.5	29.0	18.0	64.0	0.4	1.5
14C	1.5	2.5	1.0	9.5	2.0	13.0	2.0	4.5	3.5	1.5	65.0	262.5	75.0	293.0	1.8	7.0

T. EXPERIMENTAL ANALOG STATIONS AT NORSAR

Short Period Analog

As mentioned in the previous Semiannual Report (Bungum 1974), a short period analog station has been installed in subarray 05C, with the recording drum in the NORSAR Data Center. The analog high pass filter which was installed in October 1973 was removed on 8 March 1974, since the value of this filter as a local event discriminator turned out to be only marginal. The station is therefore now back to normal operation.

The problem with line outages damaging the recording equipment has been solved by limiting the maximum deflection without affecting the linearity of the recording. Also, a possibility for remote relay switching during monitoring has been implemented.

Broadband Analog (KIRNOS)

The cooperative Nordic research project involving the operation of a Kirnos station at NORSAR has continued. The installation and calibration of the instrument are described in detail by Pettersen and Larsen (1974).

It was indicated in the previous Semiannual Report (Bungum 1974) that the Kirnos recordings at NORSAR were strongly affected by microseismic disturbances with energy peaking in the middle of the passband of the instrument. This has been confirmed through another half year of operation, where the seismograms have been read in comparison with the NORSAR bulletin. Usually, there have been between 10 and 20 events identified every month (Table T.1), with somewhat more events in the summer months. However, this

TABLE T.1

Number of events identified on the KIRNOS recordings at NORSAR. The small number in April is partly explained by longer periods of non-operation. For all the time, recording has been done only 5 days per week.

Month	No. of Events
January	9
February	8
March	13
April	5
May	22
June	18

effect was smaller than could be expected by looking at the usual decrease in average noise level. Due to the broadband response of the instrument, there have been identified a variety of phases, with a dominance of the more long period ones, body phases as well as surface waves. Only for about half of the events have the first arrivals been found. Figure T.1 shows the cumulative and incremental frequency-magnitude distributions for these events, plotted against NORSAR m_b values. For the smaller events (m_b<5) there is a predominance of identification of only later long period phases, including surface waves.

Because of this long period predominance of the KIRNOS, it is a very poor instrument indeed for detection of high frequent explosions. An example of this is given in Figure T.2, which shows the only explosion identified through 6 months of operation. The detection threshold for these events seems to be around m_b=6.0.

H. Bungum
A.K. Nilsen

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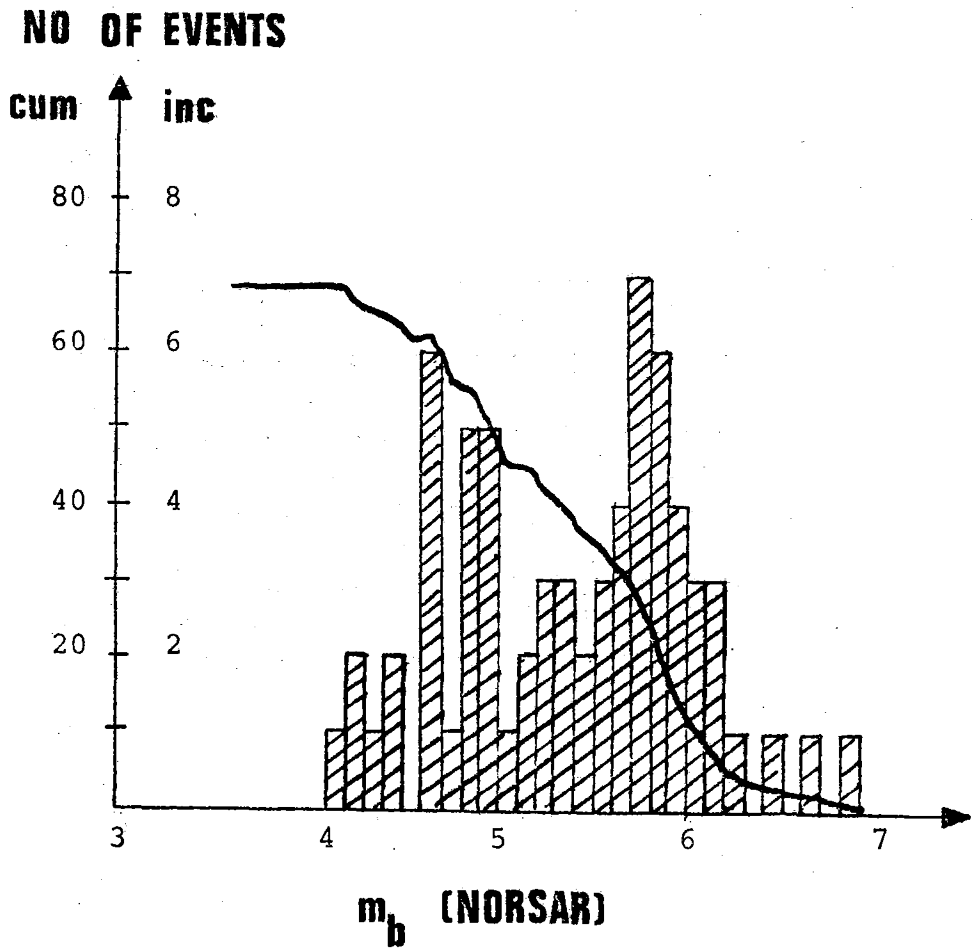

Figure T.1 Cumulative and incremental frequency-magnitude distribution of events identified on the KIRNOS recordings over a time period of 6 months (Jan-Jun 74). The NORSAR body wave magnitude is used as reference. The identification of several of the events below m_b=5.0 is relatively uncertain.

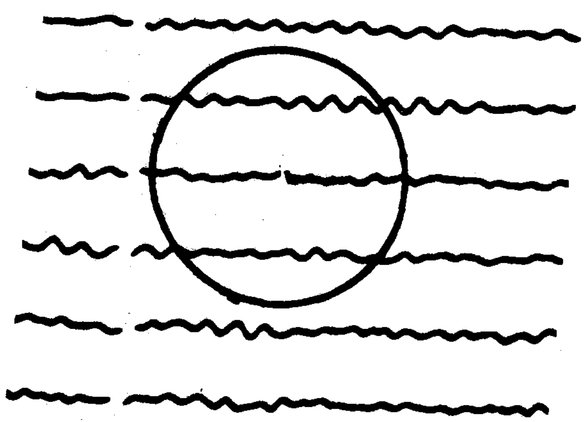

Figure T.2 KIRNOS recording of a presumed underground nuclear explosion in Eastern Kazakh on 31 May 1974, m_b=6.1.

U. ARRAY MONITORING AND FIELD MAINTENANCE

This section includes a review of actions of remote array monitoring at NORSAR Data Processing Center (NDPC) and maintenance accomplished at the subarrays and the NORSAR Maintenance Center (NMC) by the field technicians.

Subarray Monitoring Schedule

The planned schedule for the remote array monitoring (AM) has been well met. Only on one occasion were the monitoring routines delayed one week. The schedule is presented in Table U.1. The off-line computer requirement for AM is in average approximately 20 hours per month. Including the on-line tests the on-line computer time requirement is approximately 77 hours.

TABLE U.1

Monitoring Rates for AM Programs

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

Maintenance Visits

Figure U.1 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 3.2 times. The large difference from average for subarray 04B is explained by troubles in mass position (MP) bridge and appurtenant power supply (7 visits). At 05B cable breakage repair counts for four visits.

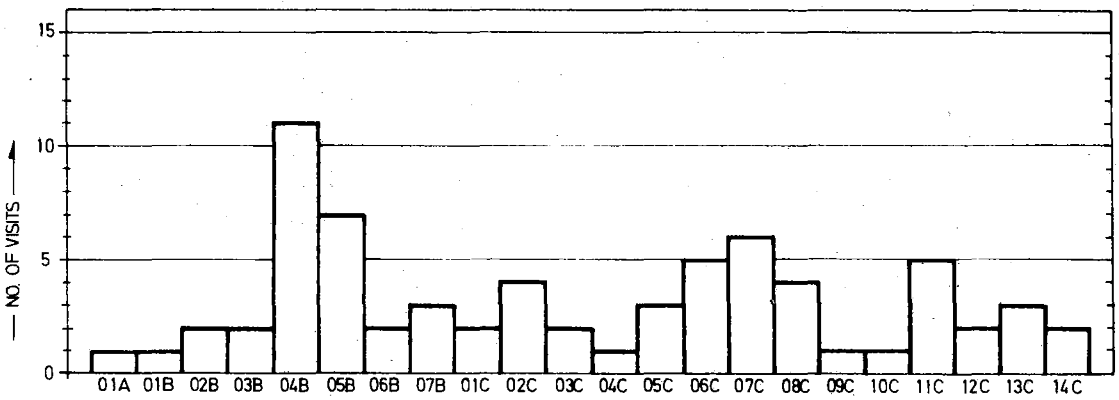

Figure U.1 Number of maintenance visits to the NORSAR subarrays, 1 January-30 June 1974.

Preventive Maintenance Projects

Work accomplished as part of this type of the preventive maintenance of NORSAR is described in Table U.2. The work at Well Head Vaults 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 U.2

Preventive maintenance accomplished at NORSAR during the period

Unit	Action	No. of Channels		Comments
		Accomp.	Remaining	
SP Seism.	Adjustment of damping	17	1	02C02; 03C01,02,05,06; 05C01,02; 06C02,03; 07C01,06; 08C01,02,05; 11C05,06; 13C05. (Remaining 10C03)
RA-5	Modification of RA-5 input card	8	2 *)	02C01,02; 03C01,02,05; 11C04,05,06. (Remaining 10C04; 12C05)
LTA	Adjustment of SP DC offset to positive bias (Ref. Larsen and Nilsen 1974)	113	-	01A; 01B; 02B01-05; 04B; 05B; 06B; 07B; 01C; 02C; 03C01,04,05; 05C; 06C; 07C01-04,06; 08C; 09C01,03-06; 10C; 11C; 12C; 13C01,02, 04-06; 14C
WHV and	Construction maintenance	30	20	02C01,02; 03C; 05C; 06C; 07C; 08C; 11C; 13C05.
RA-5	RA-5 replacement	38	22	

*) Both are modified for noise suppression, but variable damping resistance is lacking.

Disclosed Malfunctions on Instrumentation and Electronics

Table U.3 gives the number of accomplished adjustments and replacements of field equipment in the total array with the exception of those mentioned in Table U.2.

TABLE U.3

Total number of required adjustments and replacements in the NORSAR data channels, 1 January - 30 June 1974.

Unit	Characteristic	SP		LP	
		Repl.	Adj.	Repl.	Adj.
Seismometer	Damping		3		8
	RCD			5	1
Seismometer amplifier	Gain	4			
	Distortion	1			
LTA	Ch. gain		13		2
	Filter discr.	1			
	DCO	17	2		
	CMR		8		2
BE Card		15			
SLEM					
BB gen.		1	3		
SP gen.			1		
RSA/ADC		1	4		
DU		1			

Malfunctions of Rectifiers, Power Loss, Cable Breakages

No malfunctions on the subarray rectifiers have been reported. Main AC power faults caused shorter outages on four subarrays: 02B, 03B, 04B and 10C.

The cable breakage season started in the middle of May; since then eight cable breakages have occurred in all types of cables.

Workshop Repairs

All units removed from the field (refer Repl. columns in table U.3) this and previous reporting period have been repaired, with the exception of a few SP seismometers. The number of SP LTA cards taken to NMC for repair are increasing. At present 80 cards with ripple and DC offset faults are remaining at NMC. Most of these will be usable after the proposed wide-range DC offset adjustment modification is accomplished.

New Instruments and Facilities at NMC

A simulated SP subarray at NMC was taken into regular use in January when an on-line communication line, connecting NMC and NDPC was released by NTA. The possibility to pre-check components before installation in the field has been very valuable, especially during the accomplishment of the preventive maintenance program including replacement of RA-5 seismometer amplifiers.

Improvements

The status of a number of investigations to prepare lasting solutions to problems or time-consuming maintenance of certain units experienced during the operation of NORSAR is commented in Table U.4.

TABLE U.4

Status of proposed improvement 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) and at 06C (see Figure U.2).
Too low surge rating of BE protection card	Modified BE cards with 5 W wire-wound resistors are under testing at 11C on all SP channels.
False triggering of CTV water monitor	Modified prototype has been tested at 04B. A report is in print.
Trends towards negative DC offset in the SP/LTA.	Original offset trim potentiometers is replaced by 360 KΩ potentiometer, which gives adjusting range of ±135 mV (previously ±30 mV). Modification has been tested at 03B and 05C. Results are presented in Larsen and Nilsen 1974.

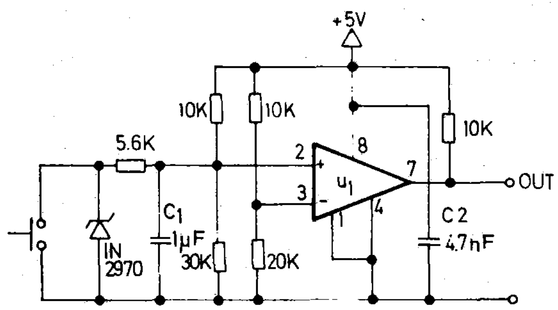

Figure U.2 Input comparator with noise filter.

Comparator U_1:	LM 311H	National Semiconductor
or	ML 311T	Microsystems International
Resistors:	All 1/4 W ± 5%	
Capacitors:	C_1 metallized mylar 100V	
	C_2 ceramic 25 or 50 V	

Conclusion

The field instrumentation and facilities are in good stanard and have operated satisfactorily throughout the period. Compared with previous periods (see Steinert and Nilsen 1973 a,b and Bungum 1974, Chapters P and Q) the corrective maintenance has been somewhat less in this period, thus indicating a stable trend. As experienced previously a seasonal instability in the LP seismometers' MP and FP has been observed during spring thaw, requiring a number of unscheduled calibrations.

The preventive maintenance program for the WHVs and RA-5s has been kept up to schedule and will be fulfilled this summer and fall.

The observation of a trend towards negative DC offsets in the SP channels, caused by a permanent change in the pre-sampling filters, has resulted in a report on a proposed modification which is necessary to restore the LTA cards taken in for "unadjustable" DC offset. An array average negative DC offset of 4 quantum units at fall 1973 has been compensated by adjusting the channel offset with positive bias whenever feasible. At the end of the reporting period the array average was nominal.

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