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12

NETWORK CAPABILITY ESTIMATION

TECHNICAL REPORT NO. 4

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

Prepared by
Nolan S. Snell

TEXAS INSTRUMENTS INCORPORATED
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Post Office Box 6015
Dallas, Texas 75222

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Program Code No. 6F10
ARPA Order No. 2551

24 September 1976

Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM and accomplished under the technical direction of the Air Force Technical Applications Center under Contract Number F08606-76-C-0011.

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405 076

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

(6) NETWORK CAPABILITY ESTIMATION. VELA Network Evaluation and Automatic Processing Research.

5. TYPE OF REPORT & PERIOD COVERED

(9) Technical rept.

6. PERFORMING ORG. REPORT NUMBER

(14) TI-ALEX(01)-TR-76-04

7. AUTHOR(s)

(10) Nolan S. Snell

8. CONTRACT OR GRANT NUMBER(s)

(15) F08606-76-C-0011, ARPA Order-2551

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Texas Instruments Incorporated
Equipment Group
Dallas, Texas 75222

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

VELA T/6705/B/ETR

11. CONTROLLING OFFICE NAME AND ADDRESS

Advanced Research Projects Agency
Nuclear Monitoring Research Office
Arlington, Virginia 22209

12. REPORT DATE

(11) 24 September 1976

13. NUMBER OF PAGES

61 (12) 62p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

Air Force Technical Applications Center
VELA Seismological Center
Alexandria, Virginia 22314

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

ARPA Order No. 2551

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

Seismology
Threshold Magnitude Estimation
Network Detection Capability
Station Ranking

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

NETWORTH is a computer program which calculates the detection and location capability of seismic networks. A modified version of NETWORTH has been developed. This program has been used to evaluate the effect of station 'downtime', the signal amplitude variance, and the station detection threshold upon network detection capability. In this version all parameters may be changed separately for individual stations. The

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capability of using signal amplitude corrections has been added. The function of amplitude corrections is to remove possible bias in the magnitude estimate due to inhomogeneous signal attenuation. These corrections may be applied to individual stations, individual epicenters, or individual station/epicenter combinations. An option has been added to calculate the effect of station 'downtime' upon network capability.

This study indicates that, if capability loss due to detection errors can be minimized, then station detection threshold and station reliability will be the fundamental limits to network performance. A baseline network of thirteen stations has been performed. These stations are as follows: Alaskan Long Period Array, (ALPA); Ankara, (ANK); Chiang Mai, (CHG); Korean Seismic Research Station, (KSRS); Large Aperture Seismic Array, (LASA); Mashhad, (MSH); Mundaring, (MUN); Norwegian Seismic Array, (NORSAR); New Delhi, (NWDEL); Red Knife, Ontario, (RK-ON); Shillong, (SHL); Taipei, (TAP); and White Horse, Yukon, (WH-YK).

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ABSTRACT

NETWORTH is a computer program which calculates the detection and location capability of seismic networks. A modified version of NETWORTH has been developed. This program has been used to evaluate the effect of station 'downtime', the signal amplitude variance, and the station detection threshold upon network detection capability. In this version all parameters may be changed separately for individual stations. The capability of using signal amplitude corrections has been added. The function of amplitude corrections is to remove possible bias in the magnitude estimate due to inhomogeneous signal attenuation. These corrections may be applied to individual stations, individual epicenters, or individual station/epicenter combinations. An option has been added to calculate the effect of station 'downtime' upon network capability.

This study indicates that, if capability loss due to detection errors can be minimized, then station detection threshold and station reliability will be the fundamental limits to network performance. A baseline network of thirteen stations has been used for this study, and a preliminary evaluation of these stations has been performed. These stations are as follows: Alaskan Long Period Array, (ALPA); Ankara, (ANK); Chiang Mai, (CHG); Korean Seismic Research Station, (KSRS); Large Aperture Seismic Array, (LASA); Mashhad, (MSH); Mundaring, (MUN); Norwegian Seismic Array, (NORSAR); New Delhi, (NWDEL); Red Knife, Ontario, (RK-ON); Shillong, (SHL); Taipei, (TAP); and White Horse, Yukon, (WH-YK).

ACKNOWLEDGMENTS

The author thanks Robert L. Sax for his many helpful suggestions during this study, and Lawrence S. Turnbull for editing the manuscript.

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SECTION I
INTRODUCTION

NETWORTH is a computer program which estimates the detection and location capability of seismic networks (Wirth, 1971). Given station parameters and epicenters, both network detection threshold magnitudes and location confidence regions are computed. The output is presented in tabular format and also plotted on a world map (via NETPLOT).

Using a modified version of NETWORTH, the individual effect of certain parameters upon network performance has been determined. These modifications are intended to provide a more realistic network evaluation. The results of this evaluation are presented in Section II. The two sections following that contain a criticism of the assumptions implicit in the NETWORTH program (Section III), and the conclusions and recommendations from this study (Section IV). An analysis of the individual stations comprising this network is included in Appendix A. The modifications to NETWORTH are documented in Appendix B.

SECTION II
PARAMETER STUDY

A. BACKGROUND

The purpose of this study was to evaluate the effect of certain parameters upon the detection capability of a seismic network. Here detection capability is defined as the lowest magnitude at which the probability of four station detections exceeds 90 percent. The parameters investigated include the station detection threshold, the station reliability, and the signal amplitude variance. Since these parameters individually have a wide range, the following plan was followed. A baseline network was established using station noise statistics furnished by Rothman (1976, personal communication). A baseline value of 0.4 was used for the standard deviation of the $\log_{10}$ signal amplitude (σ_s in magnitude units). Veith and Clawson (1972) determined that this value of σ_s was representative of the WWSSN short-period network. A baseline value of 4.0 was used for the station detection threshold (signal-to noise ratio required for detection). This detection threshold is used at NORSAR for conventional beamforming (Ringdal, 1972). The stations in the baseline network were assumed "up" at all times. Each parameter being tested was varied individually from the baseline value, and the resulting change in network detection capability was calculated. This plan has the advantages of determining the effect of each parameter uniquely and reducing the number of test runs.

The NETWORTH technique for estimating network detection capability is based on the equations summarized in Table II-1. First, the signal amplitudes at all network stations are calculated for an assumed event

TABLE II-1

EVALUATION OF NETWORK DETECTION CAPABILITY THRESHOLD MAGNITUDE DETERMINATION

$$\log_{10} A_{ij} = m_j + b_{\Delta} + c_{\Delta} \log_{10} \Delta_{ij} + E_{ij} \qquad \text{(II-1)}$$

$$p_{ij} = \Phi \left[\frac{\log_{10} A_{ij} - (\mu_N + \log_{10} \text{SDT})}{\left(\sigma_n^2 + \sigma_s^2\right)^{1/2}} \right] \qquad \text{(II-2)}$$

$$\Phi(x) = \frac{1}{2\pi} \int_{-\infty}^{x} e^{-y^2/2} \, dy \qquad \text{(II-3)}$$

$$\hat{p}_j(\geq \alpha) = \sum_{k=\alpha}^{N} \hat{p}_j(k) \qquad \text{(II-4)}$$

Symbols above are defined as follows:

A_{ij}	- signal amplitude at station i for event j (0-p)
m_j	- magnitude of event j (m_b)
b_{Δ}, c_{Δ}	- standard table entries
E_{ij}	- station-epicenter bias corrections
μ_N	- mean $\log_{10}$ noise amplitude (0-p)
σ_n^2	- variance of $\log_{10}$ noise
σ_s^2	- variance of $\log_{10}$ signal
$\Phi(x)$	- normal cumulative probability function
N	- number of stations in the network
$\hat{p}_j(k)$	- probability that k stations will detect event j
$\hat{p}_j(\geq \alpha)$	- probability that α or more stations will detect event j
SDT	- station detection threshold; i. e., signal-to-noise ratio required for detection at station.

at epicenter j with magnitude m_{bj} (equation (II-1)). The calculation of the signal amplitudes uses a standard distance-amplitude table based upon Clawson P-wave values. Signal and noise are assumed lognormally distributed in NETWORTH; hence the probability that the signal-to-noise ratio exceeds the station detection threshold is given by the normal cumulative probability function (equations (II-2) and (II-3)). In NETWORTH signal and noise are recorded zero-to-peak (0-p). The noise mean is input as the geometric mean of the noise amplitudes; the logarithm of the geometric mean gives the mean logarithm (base 10) of the noise, μ_N. The individual station detection probabilities are then combined into the network probability of at least α station detections, $\hat{p}_j(\geq \alpha)$, using a recursive relation involving the individual station detection probabilities (equation (II-4)). If the network probability of detections is less than the required probability ρ_{NET}, the event magnitude (m_{bj}) is incremented and the loop is reentered. The lowest event magnitude m_{bj} at which $p_j(\geq \alpha)$ is $\geq \rho_{NET}$ is the threshold magnitude for the j^{th} epicenter.

The baseline network was found to be adequate in locating events within Eurasia. This is evident from Figure II-1, in which the oriented crosses represent the 95 percent confidence ellipses for zero depths. The calculation of confidence regions is based upon the estimated travel time variance, which has an individual station component and a station-epicenter component derived from a standard table (Wirth, 1971). Each station was assumed to have a standard deviation of 1.0 second in timing the signals. These confidence regions are elliptical since the derivatives of the travel time variance with respect to latitude and longitude are in general not equal; varying with the epicenter/network configuration. Hence there exists for a required confidence region a direction of maximum location uncertainty and a direction of minimum location uncertainty; these are indicated by the semi-major and semi-minor axes of the 95 percent confidence regions. The confidence

TABLE II-2

BASELINE NETWORK

Station	Latitude °N	Longitude °E	Noise** Amplitude	Noise* S. D.
ALPA	65.2	147.7	0.78	0.10
ANK	39.9	-32.8	1.03	0.25
CHG	18.8	99.0	1.03	0.15
KSRS	35.5	-127.9	1.50	0.22
LASA	46.7	106.2	0.40	0.15
MSH	36.3	-59.6	1.70	0.35
MUN	32.0	-116.2	1.11	0.20
NORS	60.8	-10.8	1.00	0.15
NWDEL	28.7	-77.2	2.00	0.20
RK-ON	50.8	93.7	2.50	0.50
SHL	25.6	-91.9	2.00	0.20
TAP	25.0	-121.5	3.47	0.25
WH-YK	60.7	135.0	2.50	0.50

* S. D. = Standard Deviation (magnitude units)
** Mean (millimicrons, 0-p)

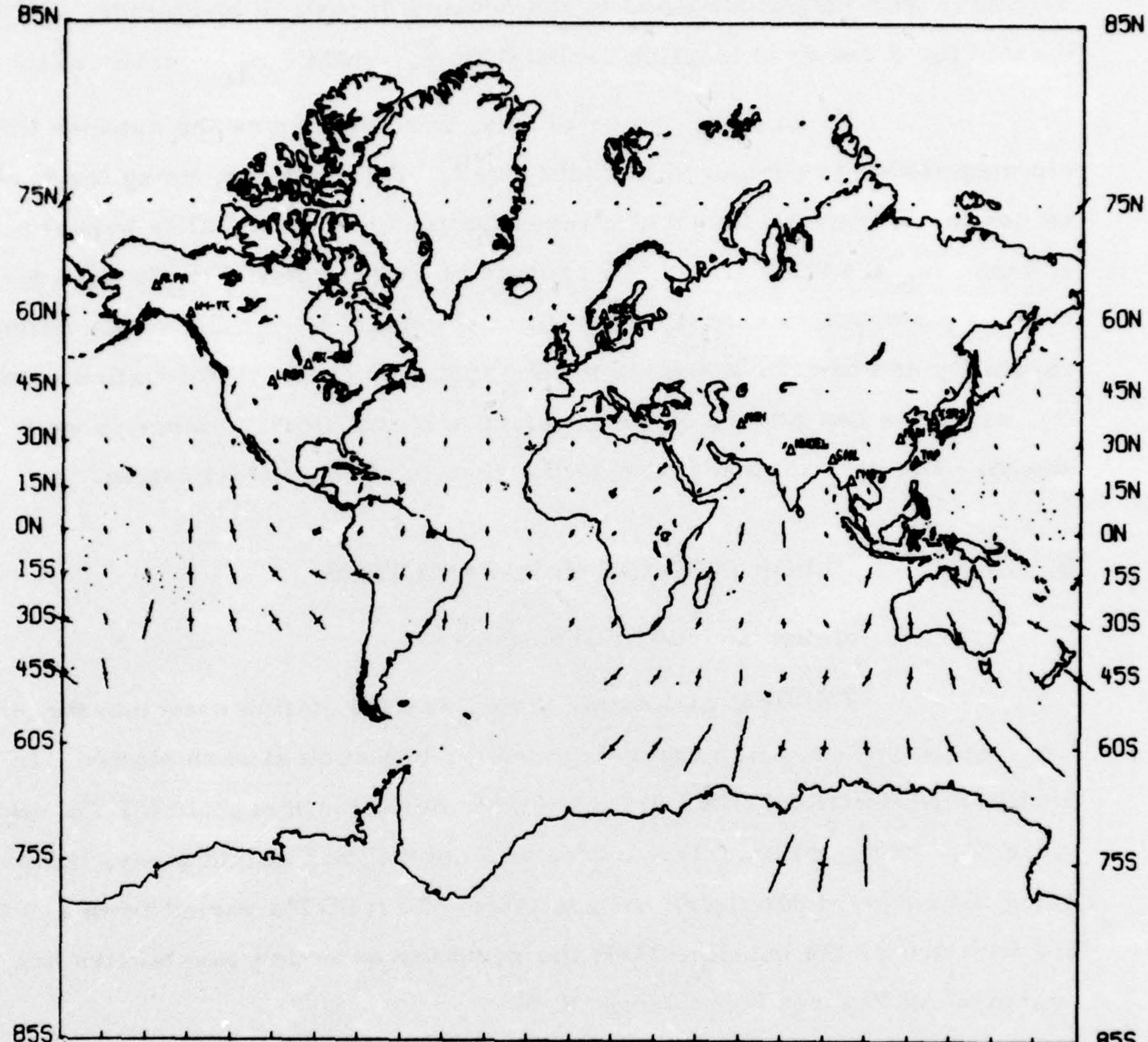

FIGURE II-1

95% CONFIDENCE REGIONS - BASELINE NETWORK
(Crosses Represent Ellipse Axes)

regions are centered upon the known epicenters. An event, occurring at each epicenter with magnitude equal to the network threshold magnitude, will be located for a required location probability p_L within p_L's error ellipse.

Event detection capability, here defined as the network threshold magnitude, is contoured in Figure II-2. This network, using the baseline values for the parameters under investigation, has a capability between m_b 4.2 and m_b 4.4 for Eurasia. A contour increment of 0.2 m_b is used for all contour plots in this report. The effect of certain parameters upon detection capability has been investigated in this study, in contrast to location capability, since the dependence of the latter upon travel time variance is well known. The next section presents the results of this investigation.

B. RESULTS FOR INDIVIDUAL PARAMETERS

1. Station Detection Threshold

The first parameter tested was the station detection threshold; i.e., the signal-to-noise ratio required for detection at each station. In the modified NETWORTH (NET 2), the station detection threshold (SDT), may be varied for each station. This option was not utilized in this study, however, since the relevant data were not available. Test SDT's varied from 1.5 to 5.0 with 4.0 as the baseline SDT; the resulting detection capabilities are contoured in Figures II-3 through II-9.

Examination of the threshold magnitudes for each epicenter revealed the following principles. The change in network threshold magnitude due to a change in SDT from SDT_1 and SDT_2 was found to be independent of epicenter and to equal $m_b = \log_{10} (SDT_1/SDT_2)$. This agrees with equations (II-1) and (II-2), from which it is seen that for a given detection probability a change in the $\log_{10}$ (SDT) is equivalent to an opposite change in threshold magnitude, m_j, for all epicenters. Thus the probability that each station detects

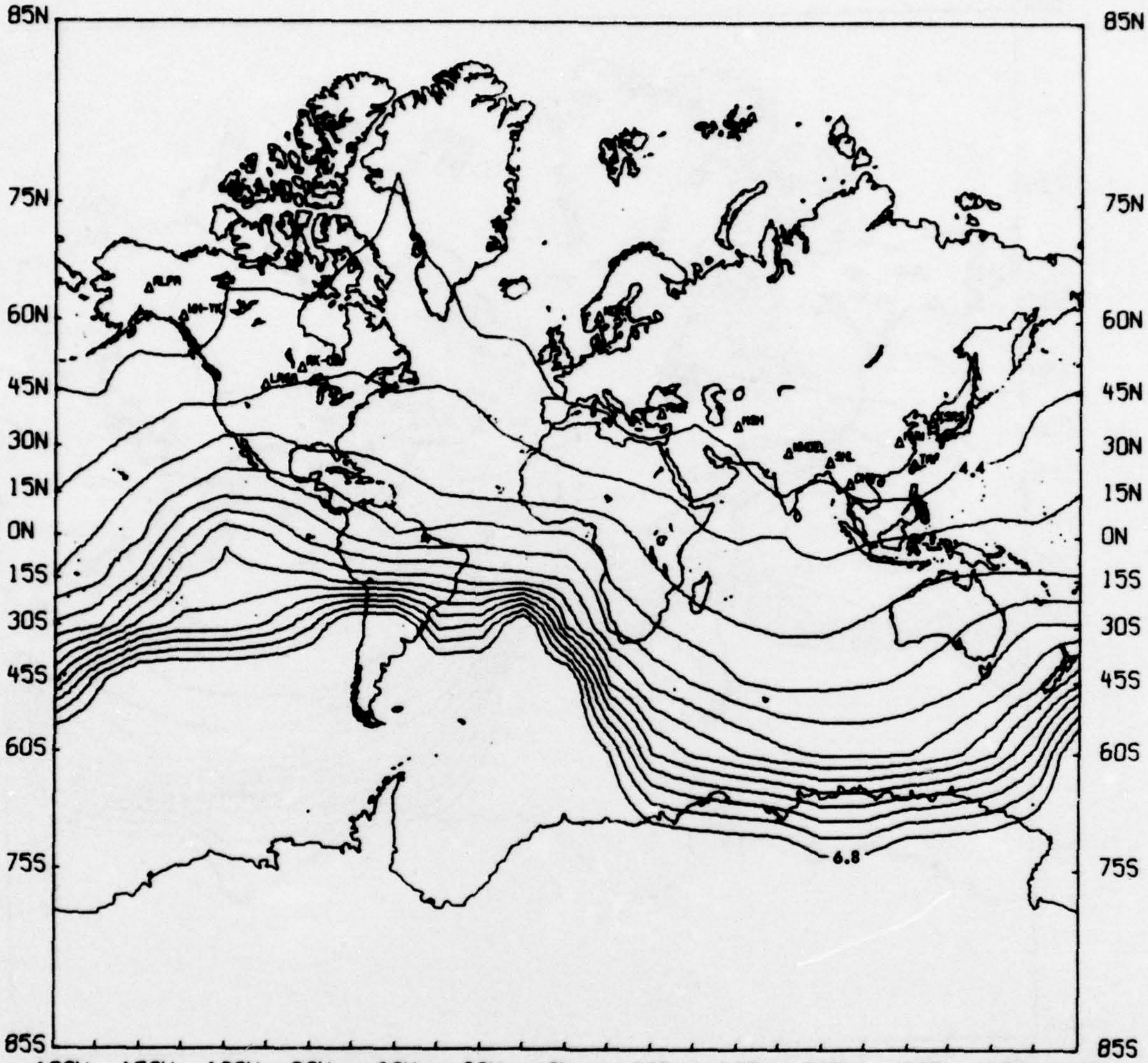

FIGURE II-2

THRESHOLD MAGNITUDE - BASELINE NETWORK

(m_b: 4.4 - 6.8)

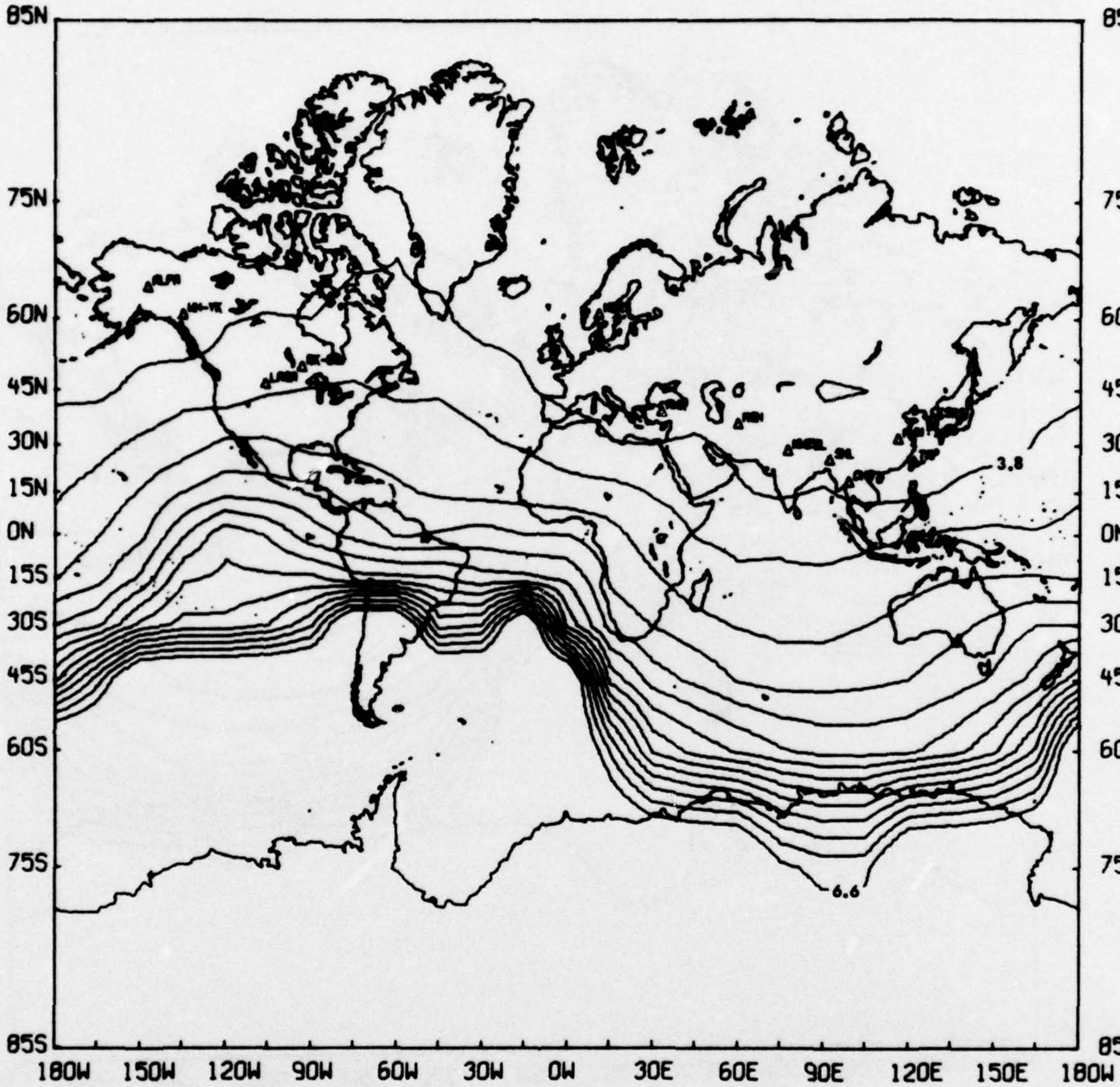

FIGURE II-3

THRESHOLD MAGNITUDE (m_b: 3.8 - 6.6):
STATION DETECTION THRESHOLD = 1.5

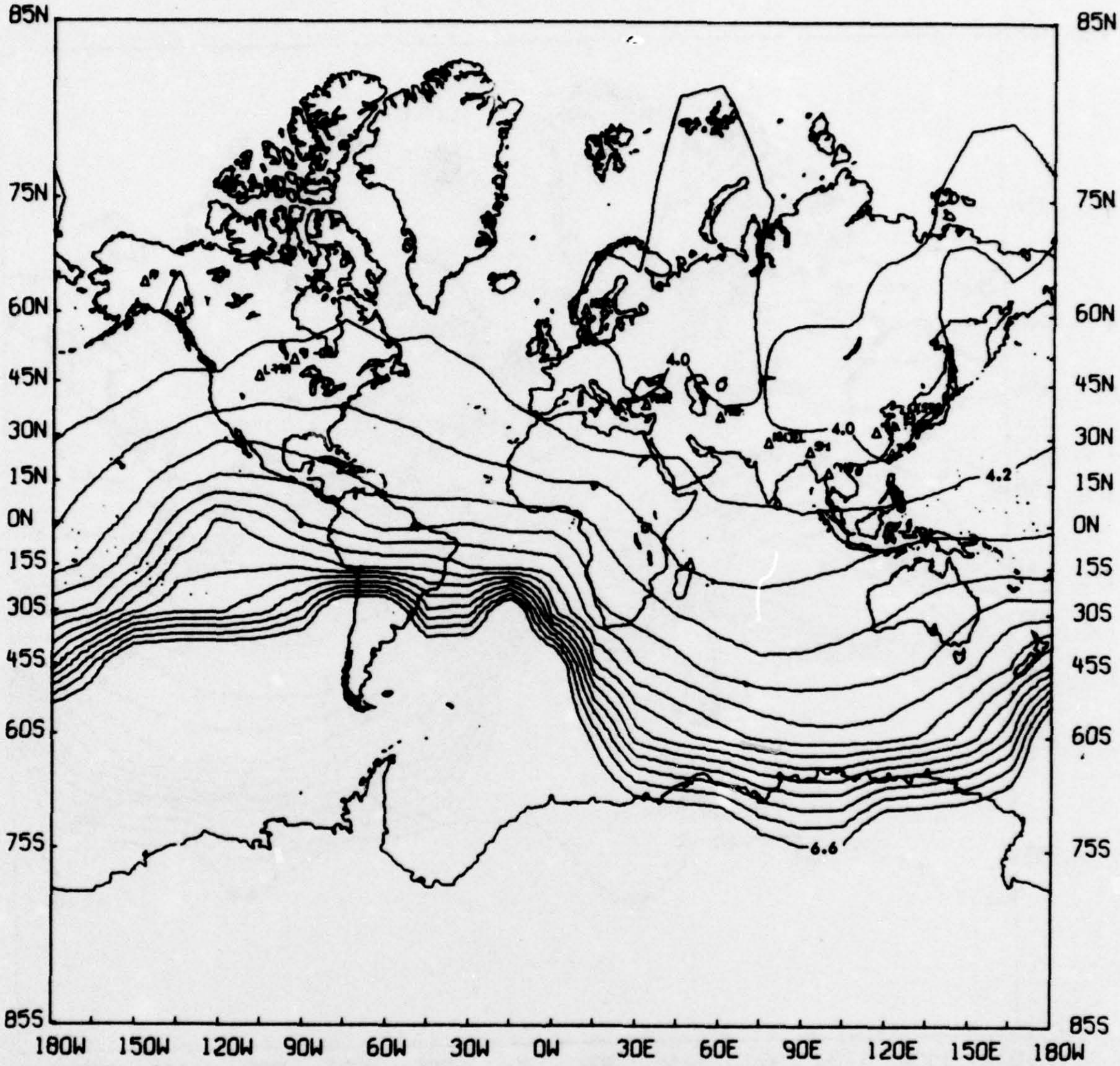

FIGURE II-4

THRESHOLD MAGNITUDE (m_b : 4.0 - 6.6):
STATION DETECTION THRESHOLD = 2.0

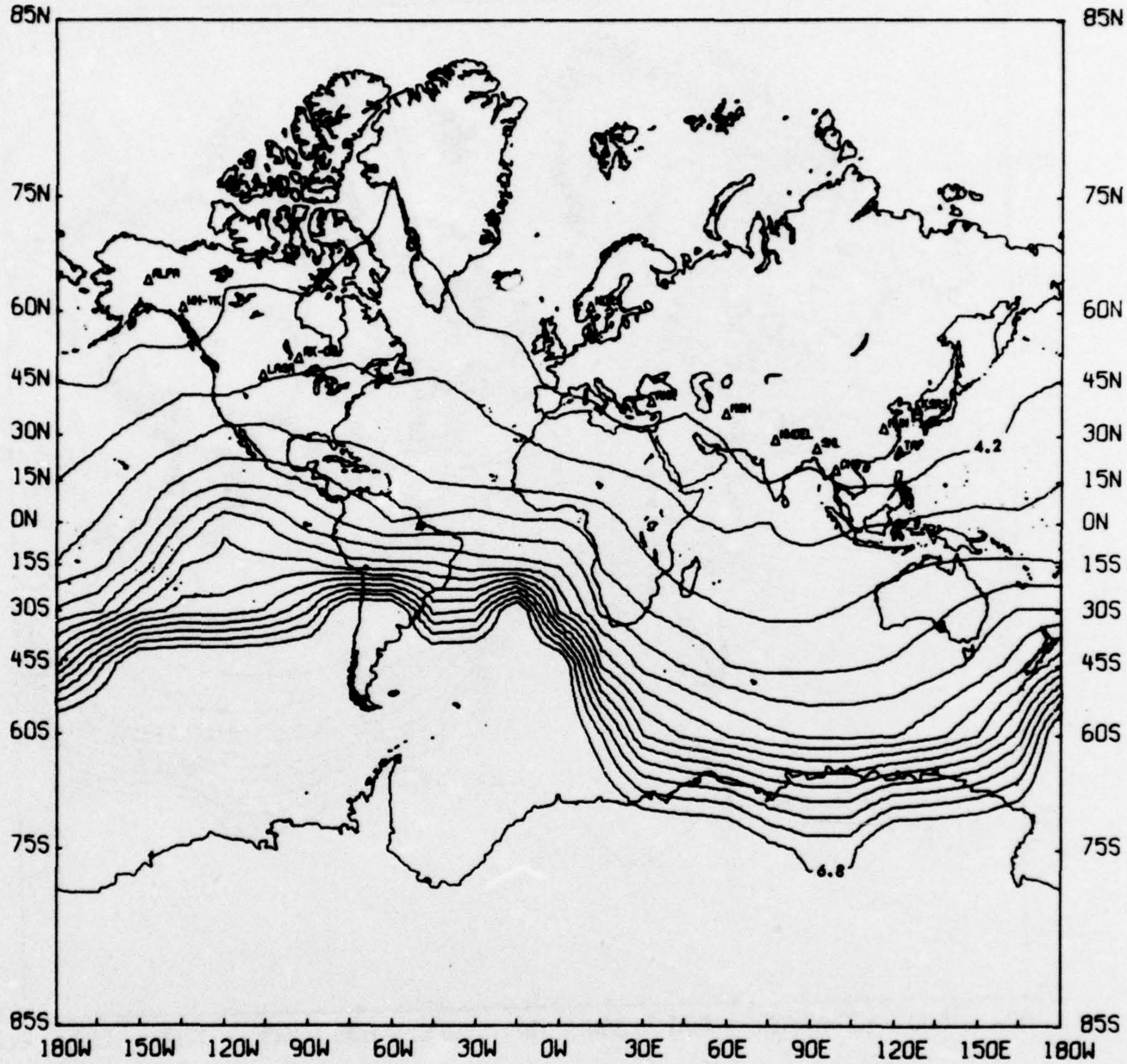

FIGURE II-5

THRESHOLD MAGNITUDE (m_b: 4.2 - 6.8):
STATION DETECTION THRESHOLD = 2.5

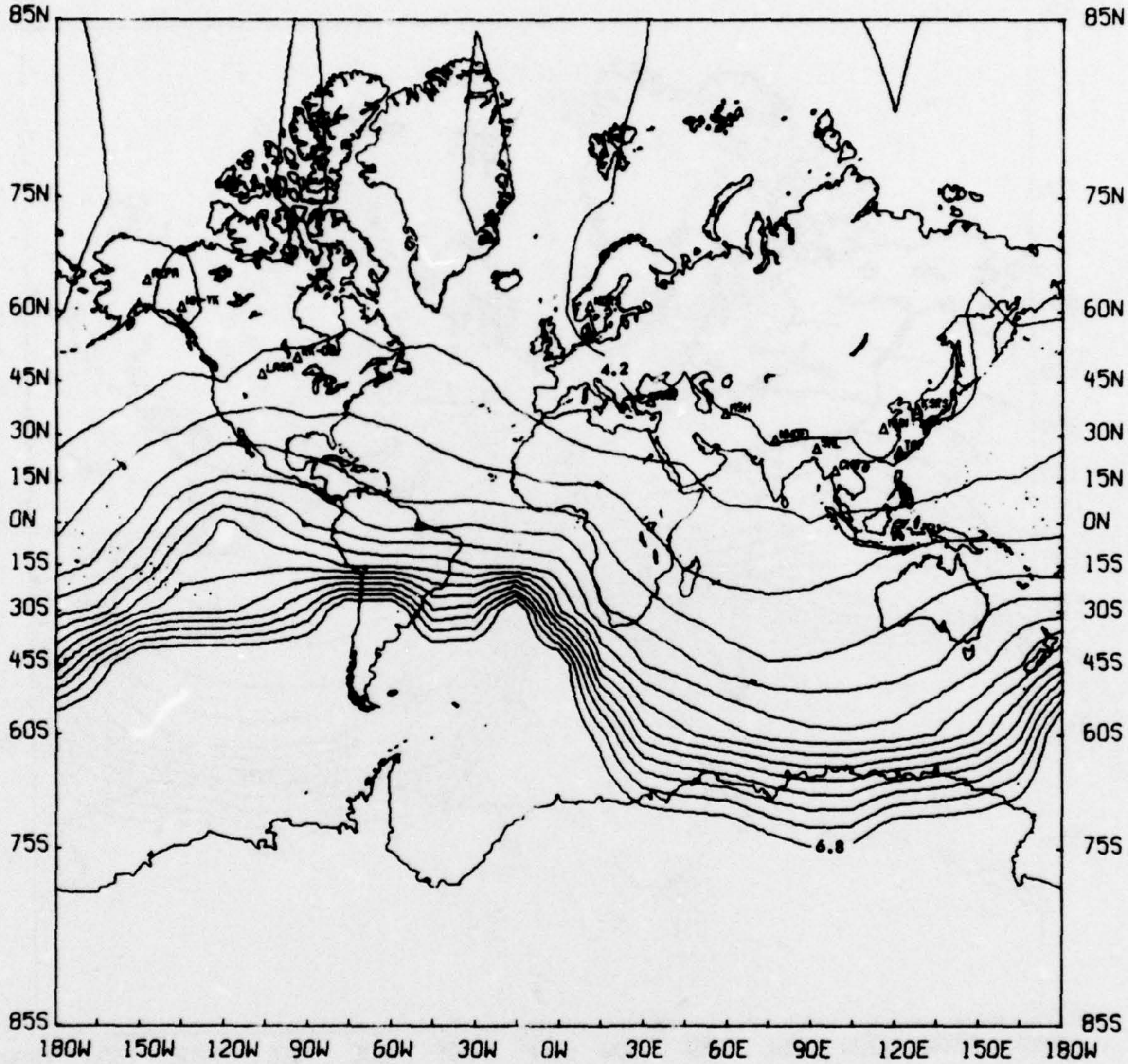

FIGURE II-6

THRESHOLD MAGNITUDE (m_b : 4.2 - 6.8):
STATION DETECTION THRESHOLD = 3.0

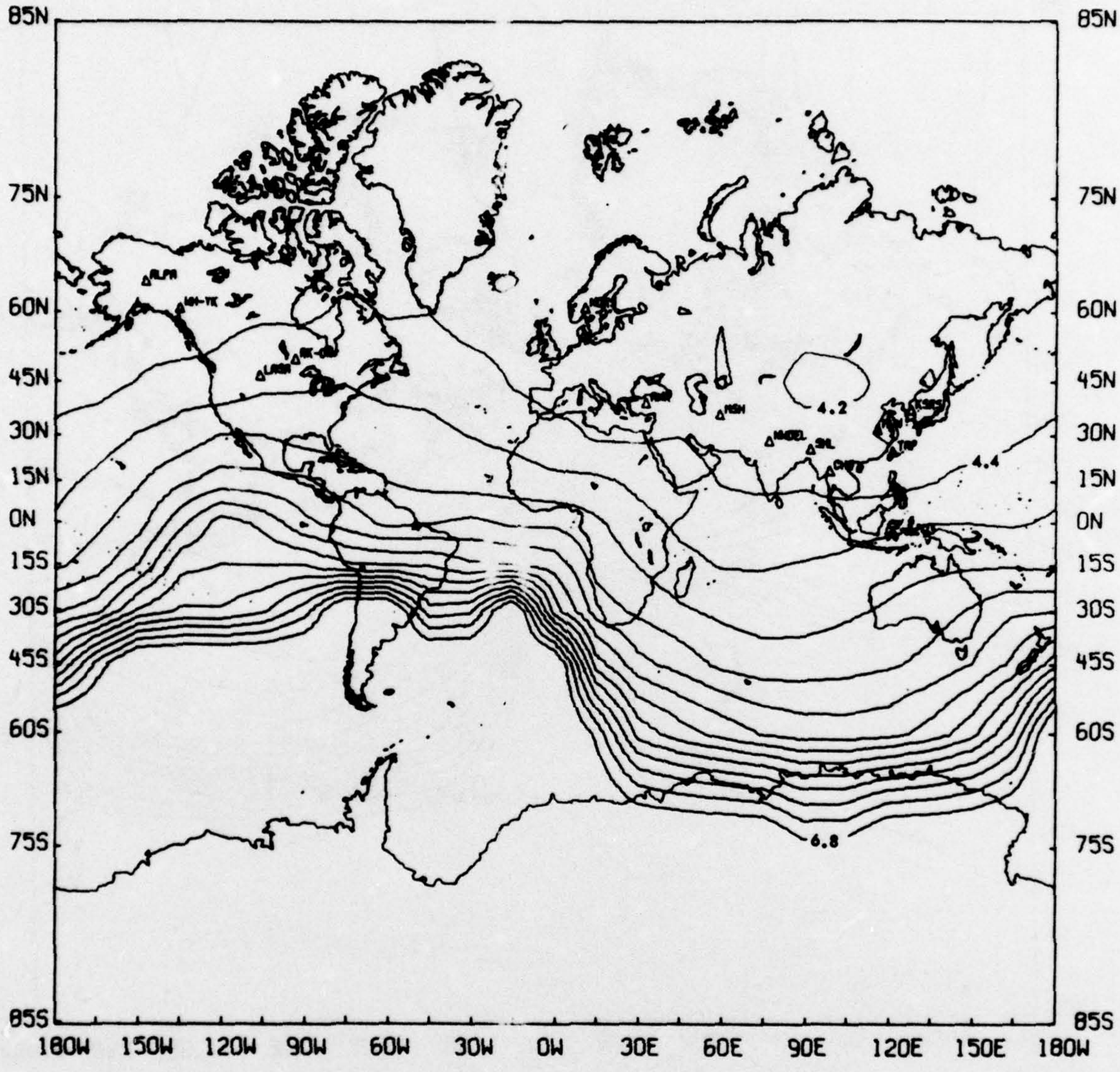

FIGURE II-7

THRESHOLD MAGNITUDE (m_b: 4.2 - 6.8):
STATION DETECTION THRESHOLD = 3.5

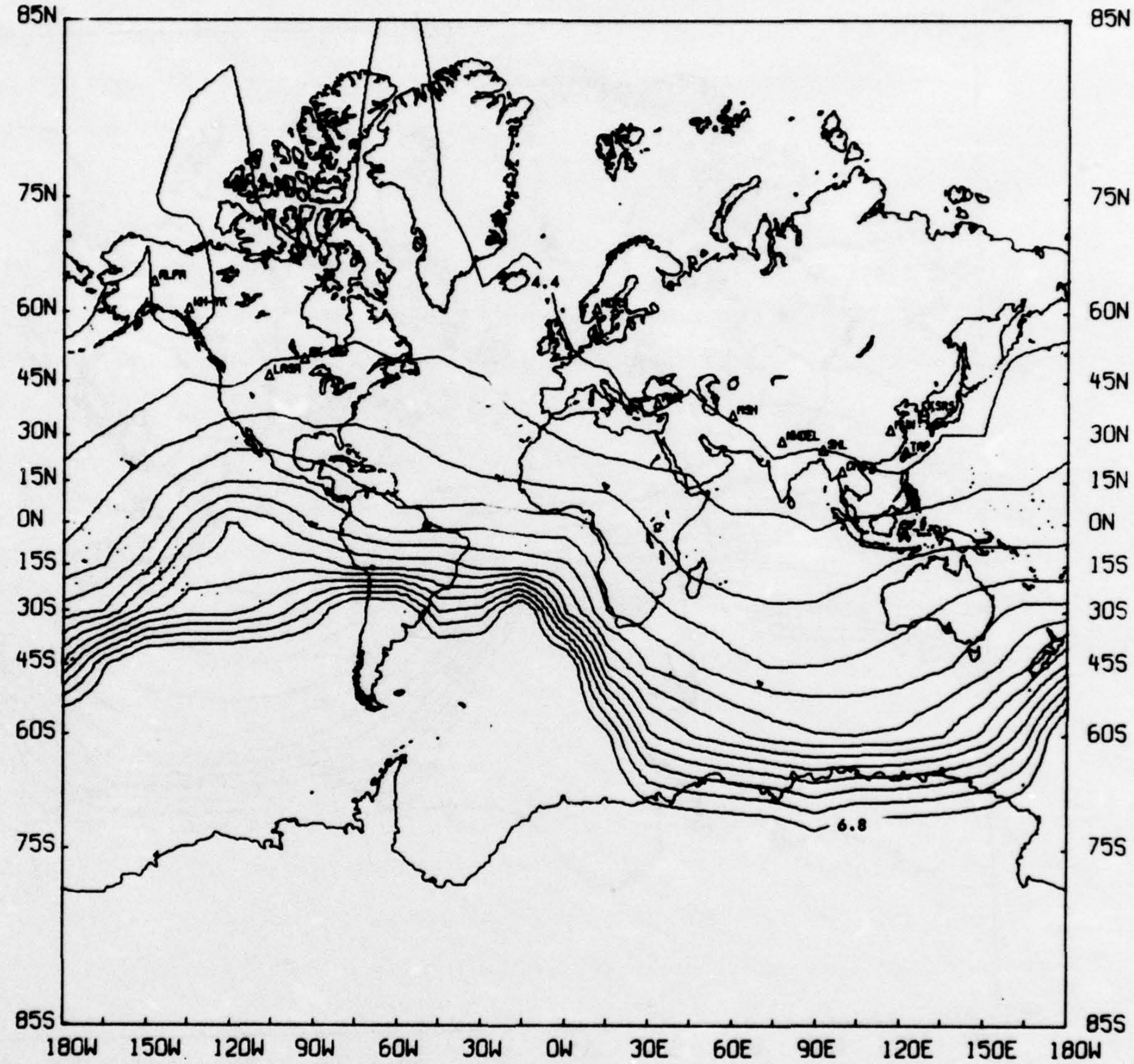

FIGURE II-8

THRESHOLD MAGNITUDE (m_b : 4.4 - 6.8):
STATION DETECTION THRESHOLD = 4.5

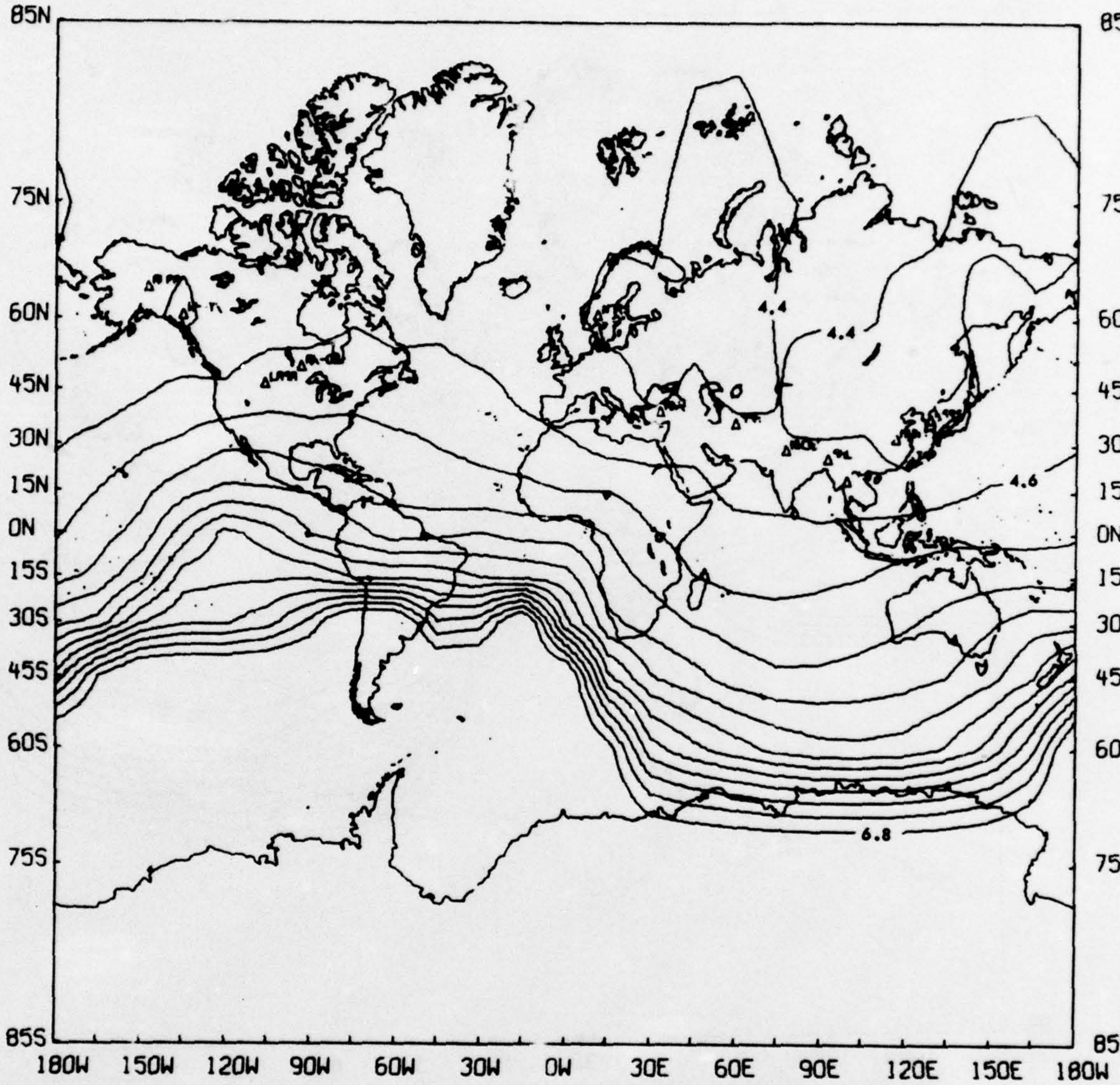

FIGURE II-9

THRESHOLD MAGNITUDE (m_b : 4.4 - 6.8):
STATION DETECTION THRESHOLD = 5.0

at the threshold magnitude was unaffected by changing the SDT at a network level. If the individual stations are ranked according to the probability that each will detect at the threshold magnitude, then changing the SDT at a network level alters the threshold magnitude by a constant but has no effect upon the relative ranking of the stations.

2. Station Reliability

For each station, reliability is defined as the probability that the station is up. The earlier NE . WORTH implicitly assumed that all stations were always up; this assumption results in an over-estimate of network capability. In NET 2 the station detection probability has been made a conditional probability, the probability that a station will detect the event if the station is up. Although reliabil ty is a station variable in NET 2, such data were unavailable at a station level. Therefore, test reliabilities were assigned at a network level, i.e., the same test reliabilities were used for all the stations. In Figure II-10, Eurasian capability loss is plotted against corresponding reliabilities.

This plot is based on Eurasia because the baseline network provides the best coverage for Eurasian surveillance. The natural redundancy of such a network means that the capability loss (due to station downtime) will increase as the epicenter moves radially away from the network center. Accordingly, for each value of reliability, there corresponds a range in capability loss. The Eurasian portion of this range appears in Figure II-10. Figures II-11 and II-12 represent threshold magnitudes for reliabilities of 0.65 and 0.80, respectively.

3. Signal Amplitude Variance

World-wide bodywave magnitudes of a given event are assumed to follow a Gaussian distribution with unknown mean μ and variance σ^2 (Herrin and Tucker, 1972). This is supported by a study done by Freedman

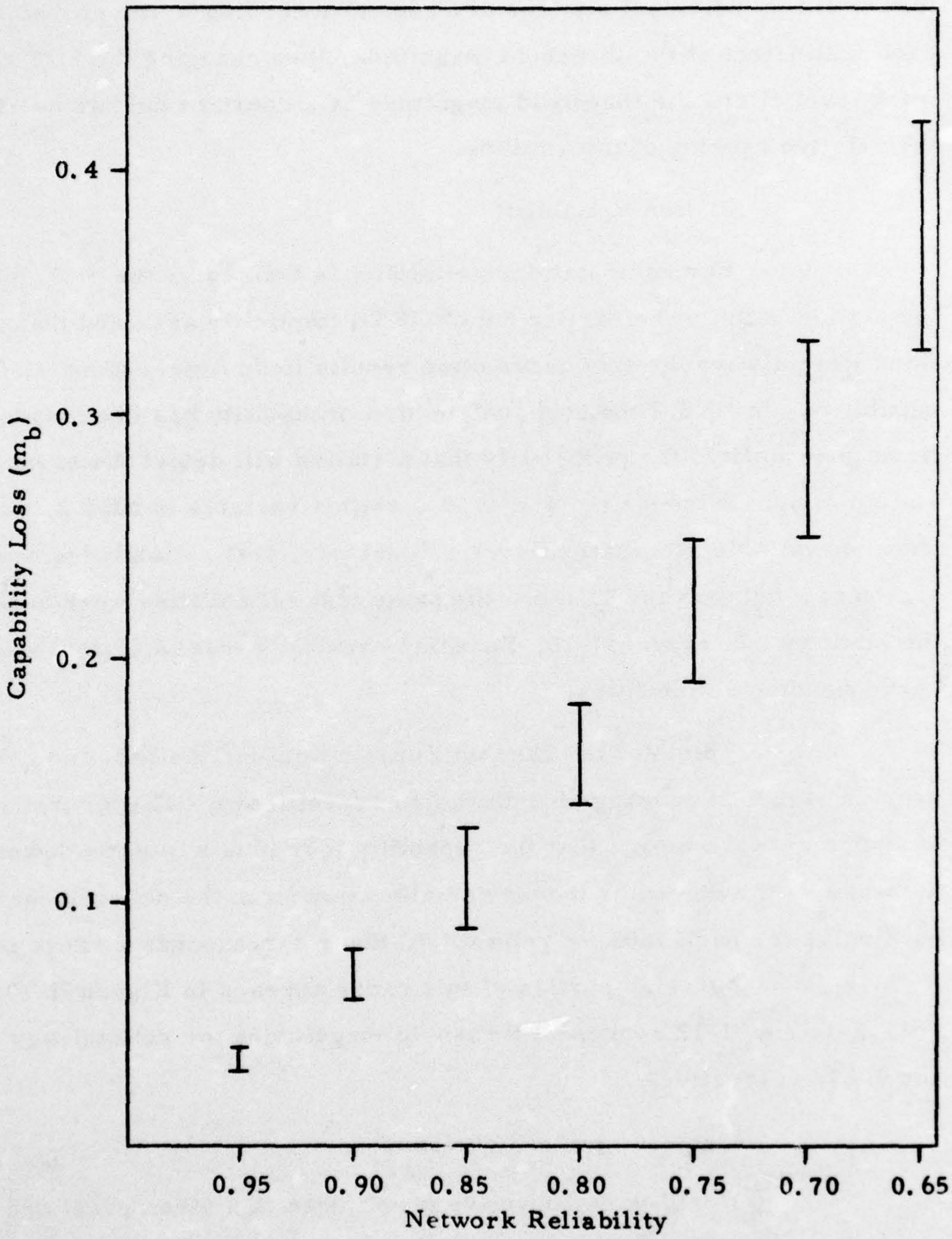

FIGURE II-10

RANGE OF CAPABILITY LOSS (m_b) FOR EURASIAN CONTINENT

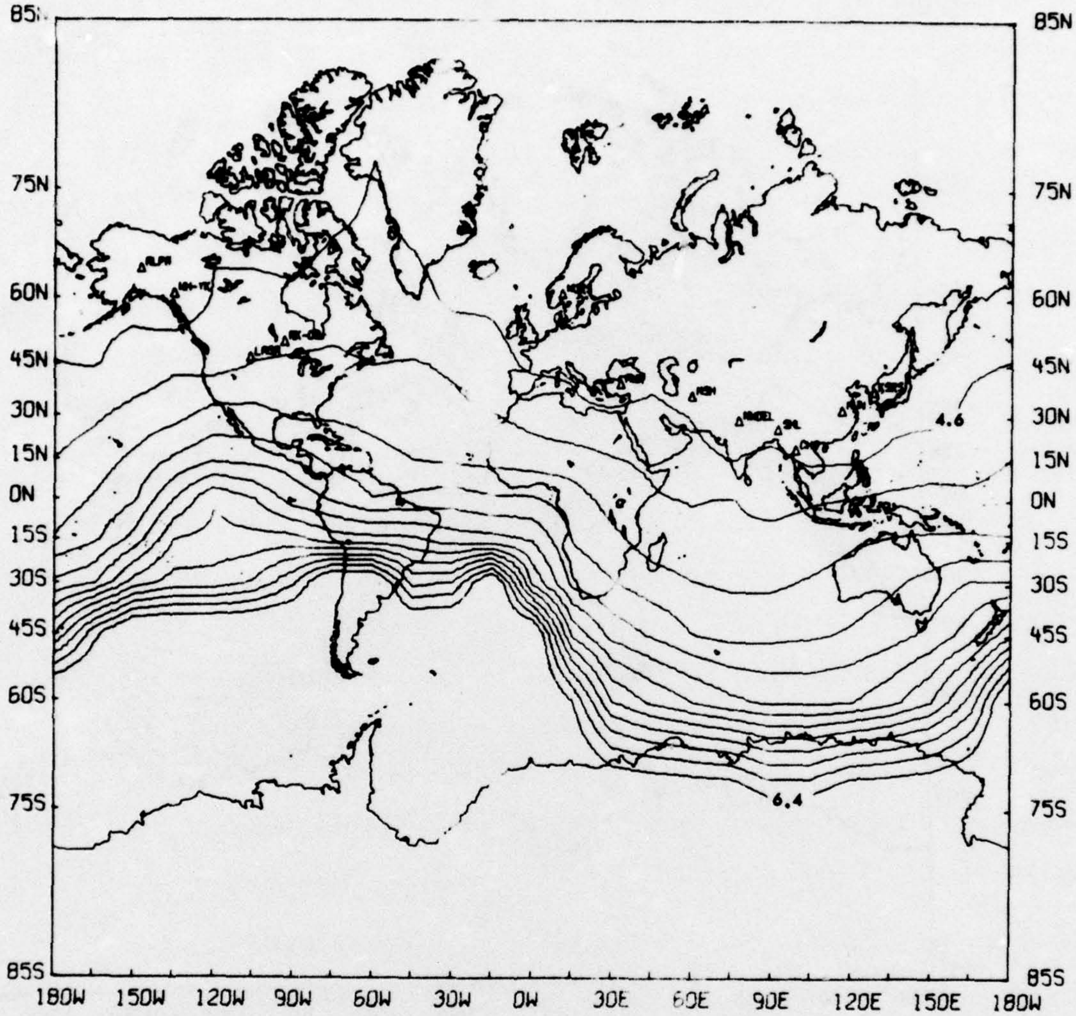

FIGURE II-11

THRESHOLD MAGNITUDE (m_b: 4.6 - 6.4):
NETWORK RELIABILITY = 0.65

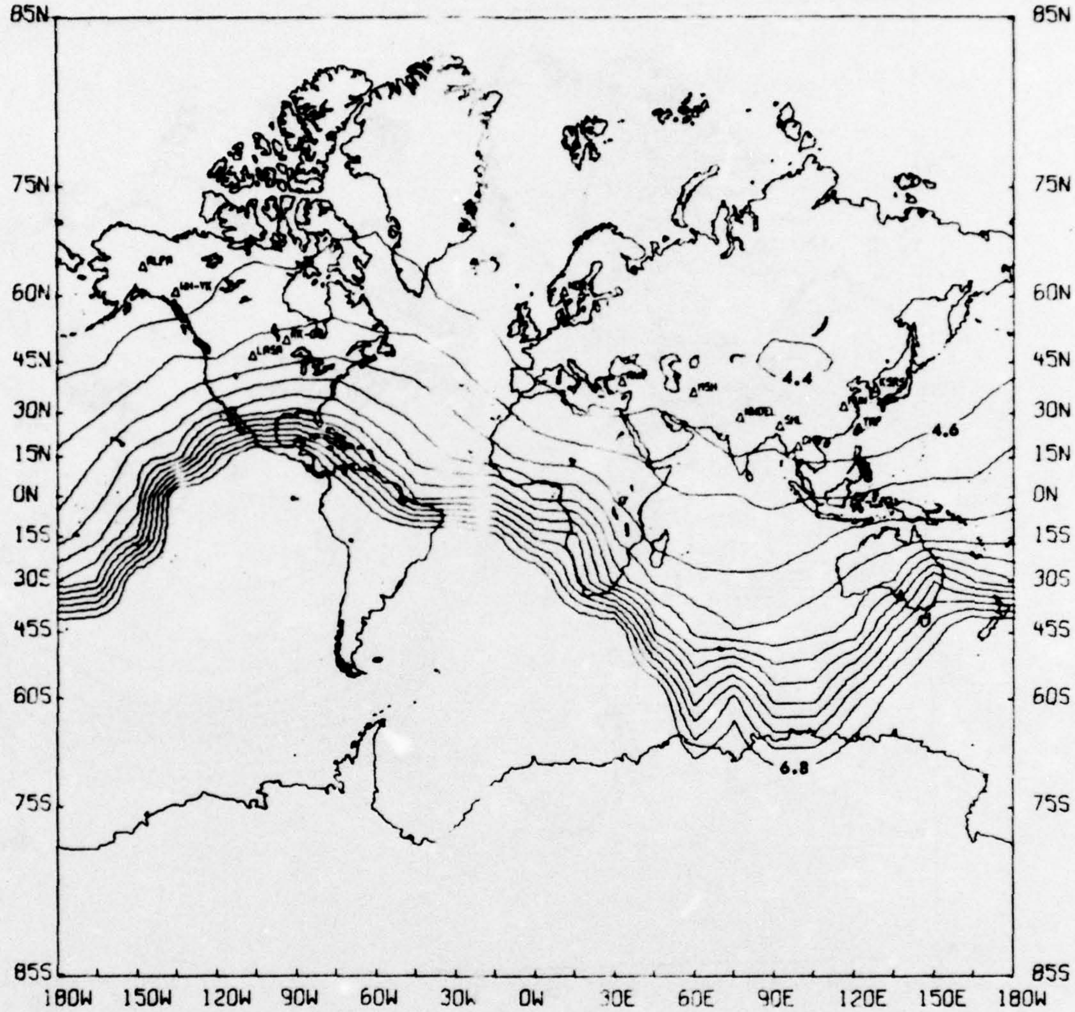

FIGURE II-12

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
NETWORK RELIABILITY = 0.8

(1967). Freedman showed that the amplitude distribution of bodywave recordings was closely approximated by a lognormal distribution; therefore, the estimated magnitude has a normal distribution. Lacoss (1972) has shown that noise also fits a lognormal distribution. These results are incorporated into the NETWORTH program in that both signal and noise are assumed lognormally distributed. The signal amplitude variance, σ_s^2, in NETWORTH is assumed independent of event magnitude. This agrees with the results of Bungum and Husebye (1974) in their comparison of NORSAR and NOAA magnitudes.

Signal detectability is strongly dependent upon site geology. Thus the use of a few reporting stations in estimating event magnitude may create bias. Ringdal (1975) and Evernden (1976) have shown that the high standard deviations of routine m_b calculations are due to systematic variations in signal amplitudes due to site locations. The possibility also exists that high signal variance may affect network detection capability. This idea may be evaluated by using range of signal variances in NETWORTH. Veith and Clawson (1972) determined that a $\sigma_s = 0.4$ was representative of the WWSSN short-period network; this value ($\sigma_s = 0.4$) was used as the baseline σ_s. Tests were run from $\sigma_s = 0.2$ to $\sigma_s = 0.6$ (Figures II-13 and II-14).

The network detection capability was unaffected by the value used for σ_s for Eurasian events; i.e., these events geographically interior to the network. The value used for σ_s affected network detection capability only for events geographically far removed from the network interior. This apparently dichotomous relationship can be explained by referring to the detector algorithm used in the NETWORTH program (equation (II-2) from Table II-1). For convenience, his algorithm shall be repeated here.

$$p_{ij} = \Phi \left[\frac{\log_{10} A_{ij} - (\mu_N + \log_{10} SDT)}{\left(\sigma_s^2 + \sigma_n^2\right)^{1/2}} \right]$$

where Φ = normal cumulative probability function.

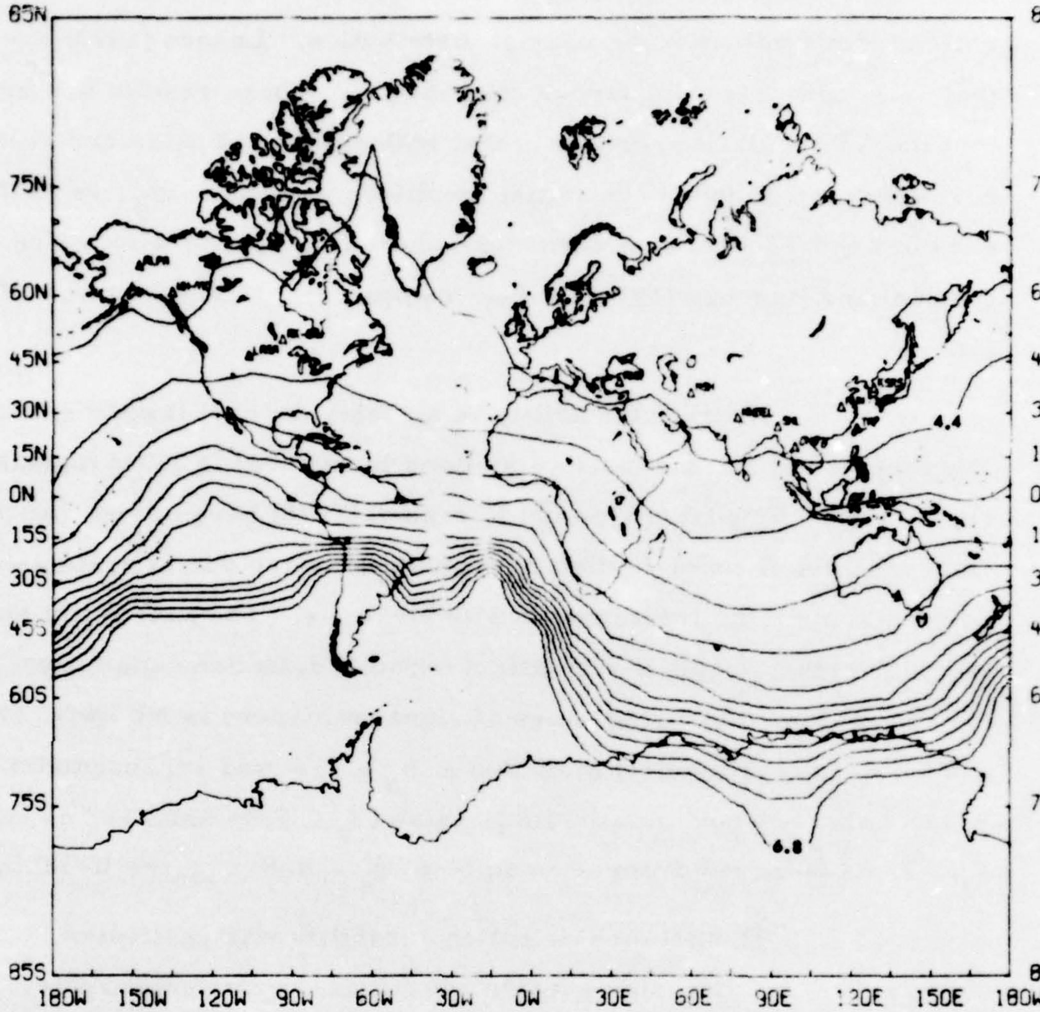

FIGURE II-13

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8): $\sigma_s = 0.2$

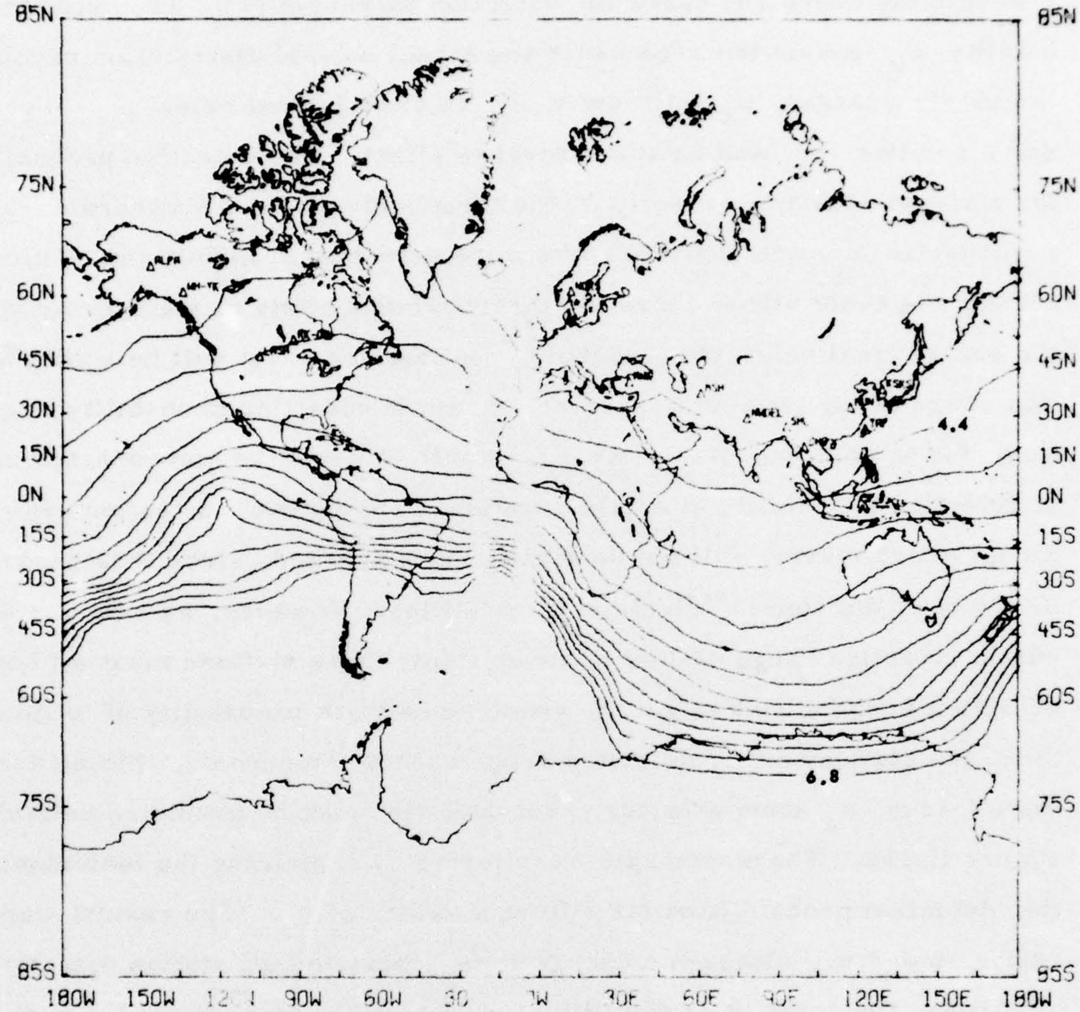

FIGURE II-14

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
$\sigma_s = 0.6$

Figures II-15a and II-15b refer to a signal whose mean is respectively above and below the detection threshold (T). The detection probability p_{ij} equals the area under the signal normal distribution beyond T. Obviously a larger σ_s will lower p_{ij} in case (a) but raise p_{ij} in case (b), and a smaller σ_s will have the reverse effect. The detection probability for a signal with mean exactly on the threshold will be 0.5 regardless of σ_s. A change in σ_s will therefore affect the detection probability of stations receiving the event signal above the threshold oppositely to stations receiving the event signal below the threshold. An interior event will be within detection range of all stations; therefore a gain in detection probability at one station, due to an unexpectedly large or small σ_s, will be compensated by a loss in detection probability at another station. The network detection probability for an interior event will not be significantly affected, since it is the sum of products of the station detection probabilities. However, an exterior event is within detection range of only a few stations; these stations must all have high detection probabilities to get the required network probability of α detections. Since the stations out of detection range cannot compensate, this means that the effect of σ_s upon exterior event detection may be predicted entirely by Figure II-15a. These concepts were tested by examining the individual station detection probabilities for different values of σ_s. The results were as anticipated; i.e., although a change in σ_s impacted all station detection probabilities, the network probability of α detections was affected only for distant events, where capability decreased as σ_s increased.

Since the detection capability for Eurasian events is the primary interest in evaluating this network, a reasonable conclusion is that this network's detection capability is insensitive to variations in σ_s. Note that a distinction must be drawn between network detection capability and network magnitude estimation. Obviously, magnitude estimation is adversely affected by high signal variances; thus bias may exist between the magnitude

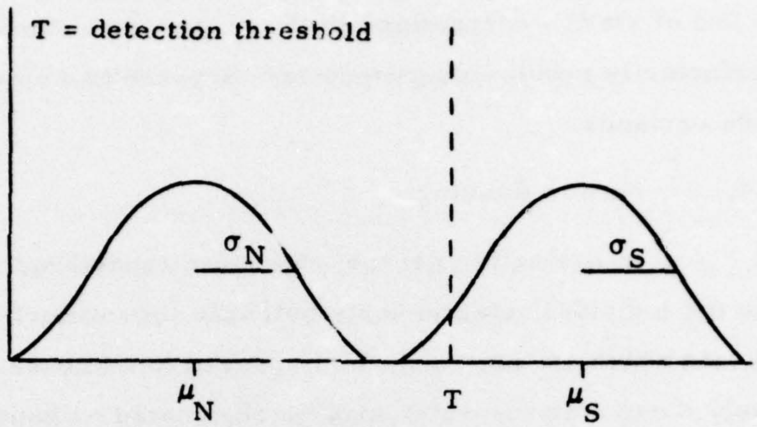

FIGURE II-15a

SIGNAL MEAN ABOVE THRESHOLD

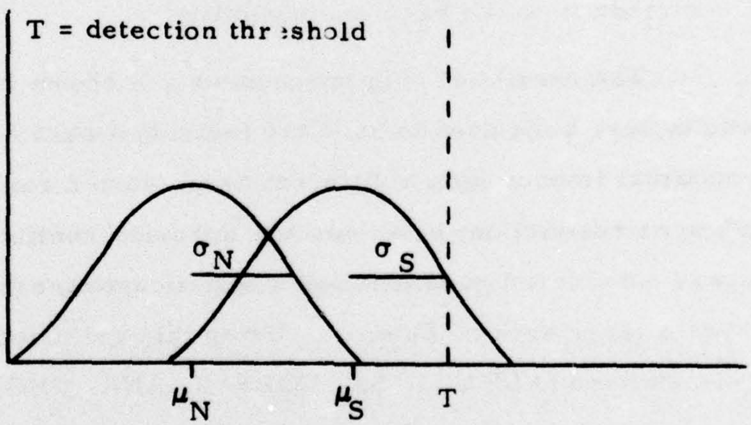

FIGURE II-15b

SIGNAL MEAN BELOW THRESHOLD

estimates of two networks for a given event. Yet the fact that the actual detection capability is relatively unaffected by higher signal variance indicates that the use of station corrections in the magnitude estimation procedures can satisfactorily resolve magnitude bias between two networks due to signal amplitude variance.

4. Station Ranking

In evaluating network detection capability, it is desirable to estimate the individual station contribution to the network capability. This will indicate which stations must be improved to increase capability, and conversely those stations which may be eliminated without significant loss. Two methods were used to estimate the individual station contribution to the baseline network. The first method was to output the individual station detection probability at the network threshold magnitude for each epicenter. The second method was to successively delete each station from the baseline network; the resulting increase in threshold magnitude then represents each station's contribution to the baseline capability.

The results of both procedures are shown in Appendix A. These results have been used to rank the individual stations. Since each station has maximal impact upon a different area, such a ranking must be qualified by an area restriction; here only the Eurasian continent was considered. A station was considered good if it had a significant threshold detection probability over a large area of Eurasia. Using this criterion, it is seen that the first six stations (ALPA, LASA, NORSAR, ANK, CHG, and MUN) are of approximately equal quality. The next four stations (KSRS, MSH, NWDEL, and SHL) are not quite as good but still contribute significantly to the network performance. The last three stations (WH-YK, RK-ON, and TAP) contribute little; furthermore, their detection probabilities are too low for these stations to act as a back-up in case a better station goes down.

SECTION III

A CRITICISM OF NETWORTH ASSUMPTIONS

The original NETWORTH has been modified to allow the user to assign all variables, including reliability at a station level. This allows a better network evaluation since real networks are inhomogeneous. However, there are still some assumptions inherent in the NETWORTH program which are questionable. These are as follows:

- NETWORTH ignores signal loss due to waveform dis-similarity across an array. The signal amplitude used in NETWORTH is calculated from tables for a given magnitude and epicentral distance. The signal amplitudes are then the same regardless of whether the receiver is an array or single site. The array gain, relative to the single site, comes from the noise reduction due to beamforming. The noise statistics are input as station parameters, although noise variations with azimuth cannot be handled. The result is that NETWORTH evaluates arrays on the basis of their noise reduction while ignoring the signal loss due to beamforming.

- The station detection thresholds in NETWORTH, (SDT), are not assigned on the basis of false alarm rate. A detection threshold which may seem desirably low from a NETWORTH evaluation may yield a higher false alarm rate than the total system can tolerate.

- NETWORTH assumes perfect association of station detection bulletins at the network level. Association refers to the process of calculating the event parameters from the relevant station detection bulletins. Uncertainties in measurement at the station level can yield false associations. This problem is compounded as the false alarm rate increases; hence there exists an optimum false alarm rate for a given network. A false alarm rate higher than the optimum will result in more events being missed due to false associations than gained by lowering the threshold (Sax and Shoup, 1974). Station detection thresholds then should be set from network considerations.

Such considerations are neglected in NETWORTH. The events are laid out on grid points and the network detection probability for each event is calculated. This is seen to be opposite to the real world process of event determination through bulletin association. If perfect bulletin association in the real world is done, then real capability might approximate NETWORTH capability. Perfect association requires either infinite resolution in the station measurements or a false alarm rate low enough to avoid ambiguity due so imprecise measurements. The usual errors in azimuth, ray parameter, possible gross timing errors, and mis-identification rule out the first alternative. The second alternative is equivalent to the second assumption listed above; i.e., the threshold must be set on the basis of the tolerable network false alarm rate. Since a lower threshold results in a higher false alarm rate, the best way to increase network detection capability is to implement effective association algorithms.

In summary, NETWORTH consistently overestimates network capability because it neglects certain network problems. These problems have been addressed by others, primarily Sax (1974) in his network simulator. Hence it is recommended that NETWORTH be remodeled using these concepts.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to estimate the effect of certain parameters upon network detection capability. The station detection threshold (SDT) and the station reliability were found to be the more critical parameters. Changing the station detection threshold altered the network magnitude detection capability by a constant; this constant equalled the logarithm of the ratio of the two thresholds. The relative ranking of the individual stations was unaffected by changing the SDT at a network level. Station reliability was found to have significant impact upon network capability; capability loss exceeded 0.4 m_b as reliability, (or percentage of station uptime) dropped below 70%. Changes in the signal amplitude variance (σ_s^2) had little effect upon detection capability for Eurasian events. For events far removed from the network interior, detection capability decreased as σ_s^2 increased. However, since the network examined is primarily designed for Eurasian surveillance, this network can be considered insensitive to changes in σ_s^2.

An analysis of the assumptions inherent in the NETWORTH program yield the following recommendations for future study:

- Evaluating the effect of the signal variance upon other networks to determine if networks in general are insensitive to the signal variance.
- Using a NETWORTH type program to evaluate different station detector threshold strategies (e.g., minimum cost, constant threshold, constant false alarm rate).

- Utilizing the modified NETWORTH, which allows parameters to be changed at a station instead of a network level, in order to estimate more realistic network capabilities.
- Adding algorithms to make NETWORTH responsive to the following problems:
  - Signal loss across an array
  - Allowable false alarm rates
  - Network capability loss due to false association of station bulletins.

SECTION V
REFERENCES

Bungum, H., and E. S. Husebye, 1974, Analysis of the Operational Capabilities for Detection and Location of Seismic Events at NORSAR, Bulletin Seismological Society of America, 64, 637-656.

Evernden, J. F., and W. M. Kohler, 1976, Bias in Estimates Of m_b At Small Magnitudes, Pre-Print.

Freedman, H., 1967, Estimating Earthquake Magnitude, Bulletin Seismological Society of America, 57, 747-760.

Herrin, E., and W. Tucker, 1972, On the Estimation of Bodywave Magnitude, Technical Report to AFOSR, Dallas Geophysical Lab., Southern Methodist University, Dallas, Texas.

Lacoss, R. T., 1972, Variations of False-Alarm Rates at NORSAR, Massachusetts Institute of Technology, Lincoln Lab.

Ringdal, F., E. S. Husebye, and A. Dahle, 1972, Event Detection Problems Using a Partially Coherent Seismic Array, NORSAR Technical Report 45.

Ringdal, F., 1975, Maximum Likelihood Estimation of Seismic Event Magnitude from Network Data, Technical Report No. 1, Texas Instruments Report No. ALEX(01)-TR-75-01, AFTAC Contract Number F08606-75-C-0029, Texas Instruments Incorporated, Dallas, Texas.

Sax, R. L., and Staff, 1974, Seismic Network System Study, Special Report No. 17, Texas Instruments Report No. ALEX(01)-STR-74-01, Contract Number F33657-72-C-0725, Texas Instruments Incorporated, Dallas, Texas.

Shoup, E., and R. L. Sax, 197·, Simulation of a World-Wide Seismic Surveillance Network, Tecl nical Report No. 13, Texas Instruments Report No. ALEX(01)-TR-74-13, AFTAC Contract Number F33657-72-C-0725, Texas Instruments Incorporated, Dallas, Texas.

Veith, K. F., and G. E. Clawson, 1972, Magnitude from Short-Period P-Wave Data, Bulletin Sei mological Society of America, 62, 435-452.

Wirth, M., 1971, Estimation o NETWORK Detection and Location Capability, Seismic Data Laborator , Research Memorandum, Alexandria, Virginia.

APPENDIX A

INDIVIDUAL STATION DETECTION CAPABILITY

This appendix contains the results used to rate the stations contained in the baseline network. Two formats are used: tables and contour plots. There is a table for each station. Each table refers to a block of sixty five epicenters which primarily cover Eurasia. Epicenters are identified by their latitude and longitude. The latitude range (15°N-75°N) is shown across the top of each table. The longitude range (0°E-180°E) is shown down the left side of each table. For a table L (refering to station L) the following data are presented for each epicenter:

(1) Network threshold magnitude

(2) Probability that station L will detect the network threshold magnitude

(3) Resulting network threshold magnitude if station L were deleted from the network.

It is seen that (2) and (3) represent roughly equivalent evaluations of each station. If a station with higher detection probability is deleted from the network, the capability loss is seen to be greater. As an extension of (3) the threshold contour plots obtained from deleting each station from the network follow that station's table; this permits a simpler visual representation of each station's contribution to the total network capability. The contour plots are less precise, however, since the contour is incremental in nature.

TABLE A-1

INDIVIDUAL STATION DETECTION CAPABILITY AT NETWORK THRESHOLD MAGNITUDE

ALPA

	15 N	30 N	45 N	60 N	75 N
0 E	4.71 .29 4.74	4.53 .655 4.[illegible]1	4.37 .593 4.44	4.34 .643 4.41	4.33 .694 4.41
15 E	4.71 .11[illegible] 4.72	4.43 .534 4.[illegible]9	4.38 .586 4.44	4.26 .558 4.33	4.33 .692 4.4[illegible]
30 E	4.61 .03[illegible] 4.62	4.43 .514 4.[illegible]8	4.26 .463 4.31	4.[illegible]9 .584 4.35	4.32 .684 4.39
45 E	4.57 .044 4.57	4.46 .548 4.[illegible]1	4.34 .544 4.39	4.[illegible]6 .555 4.32	4.27 .646 4.35
60 E	4.44 .082 4.45	4.39 .519 4.45	4.24 .464 4.29	4.[illegible]6 .567 4.32	4.27 .638 4.34
75 E	4.40 .200 4.41	4.31 .457 4.36	4.30 .538 4.35	4.[illegible]1 .629 4.37	4.30 .658 4.37
90 E	4.44 .427 4.49	4.32 .492 4.37	4.21 .469 4.25	4.31 .649 4.39	4.31 .661 4.38
105 E	4.37 .486 4.43	4.32 .529 4.3[illegible]	4.23 .514 4.27	4.31 .669 4.38	4.31 .648 4.37
120 E	4.38 .541 4.45	4.23 .475 4.28	4.29 .605 4.34	4.28 .648 4.34	4.32 .420 4.38
135 E	4.44 .635 4.51	4.35 .628 4.42	4.25 .604 4.31	4.29 .636 4.35	4.30 .749 4.39
150 E	4.53 .743 4.62	4.35 .660 4.[illegible]2	4.33 .690 4.40	4.34 .619 4.4[illegible]	4.28 .937 4.40
165 E	4.53 .771 4.63	4.44 .764 4.[illegible]3	4.38 .713 4.46	4.31 .948 4.43	4.28 .908 4.39
180 E	4.60 .836 4.73	4.48 .814 4.[illegible]9	4.41 .754 4.49	4.32 .765 4.4[illegible]	4.30 .727 4.38

INDIVIDUAL STATION DETECTION CAPABILITY AT NETWORK THRESHOLD MAGNITUDE

LASA

	15 N	30 N	45 N	60 N	75 N
0 E	4.71 .852 4.84	4.53 .866 4.64	4.37 .815 4.47	4.34 .831 4.44	4.33 .858 4.43
15 E	4.71 .309 4.74	4.43 .735 4.51	4.38 .790 4.47	4.26 .755 4.36	4.33 .844 4.42
30 E	4.61 .0 4.61	4.43 .468 4.47	4.26 .668 4.34	4.29 .758 4.38	4.32 .828 4.41
45 E	4.57 .0 4.57	4.46 .119 4.47	4.34 .687 4.41	4.26 .718 4.34	4.27 .793 4.37
60 E	4.44 .0 4.44	4.39 .012 4.39	4.24 .558 4.30	4.26 .711 4.34	4.27 .786 4.36
75 E	4.40 .0 4.40	4.31 .004 4.31	4.30 .586 4.36	4.31 .749 4.39	4.30 .804 4.38
90 E	4.44 .0 4.44	4.32 .010 4.32	4.21 .530 4.26	4.31 .754 4.39	4.31 .813 4.40
105 E	4.37 .0 4.37	4.32 .105 4.33	4.23 .601 4.28	4.31 .762 4.39	4.32 .817 4.39
120 E	4.38 .0 4.38	4.23 .343 4.27	4.29 .698 4.36	4.28 .753 4.36	4.30 .832 4.41
135 E	4.44 .231 4.46	4.35 .691 4.42	4.25 .697 4.32	4.29 .781 4.37	4.30 .832 4.40
150 E	4.53 .781 4.63	4.35 .759 4.43	4.33 .790 4.41	4.34 .835 4.43	4.28 .832 4.39
165 E	4.53 .868 4.65	4.44 .852 4.54	4.38 .854 4.48	4.31 .842 4.42	4.28 .844 4.38
180 E	4.60 .923 4.74	4.48 .903 4.60	4.41 .892 4.51	4.32 .868 4.42	4.30 .864 4.39

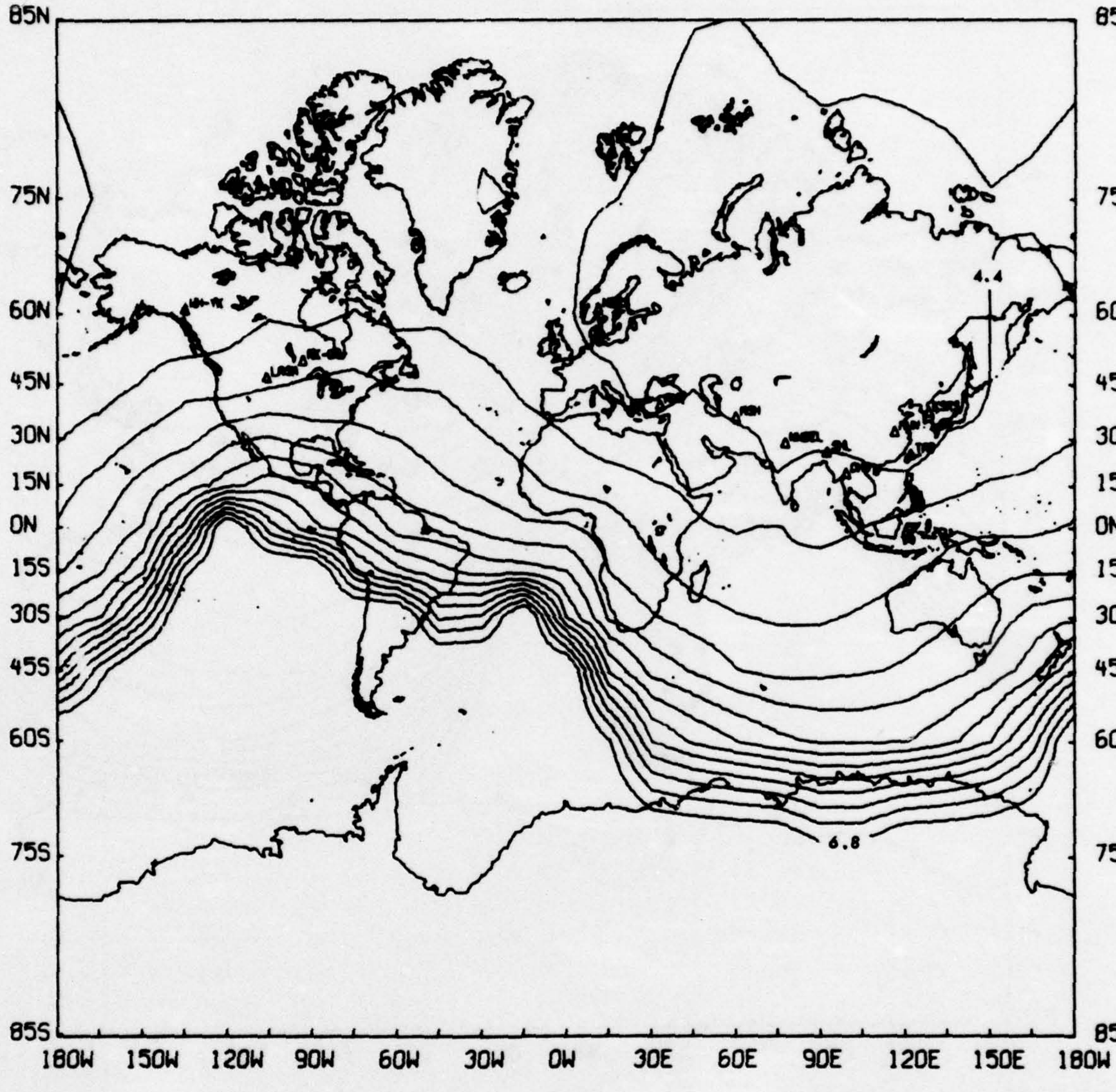

FIGURE A-1

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
ALPA DELETED FROM NETWORK

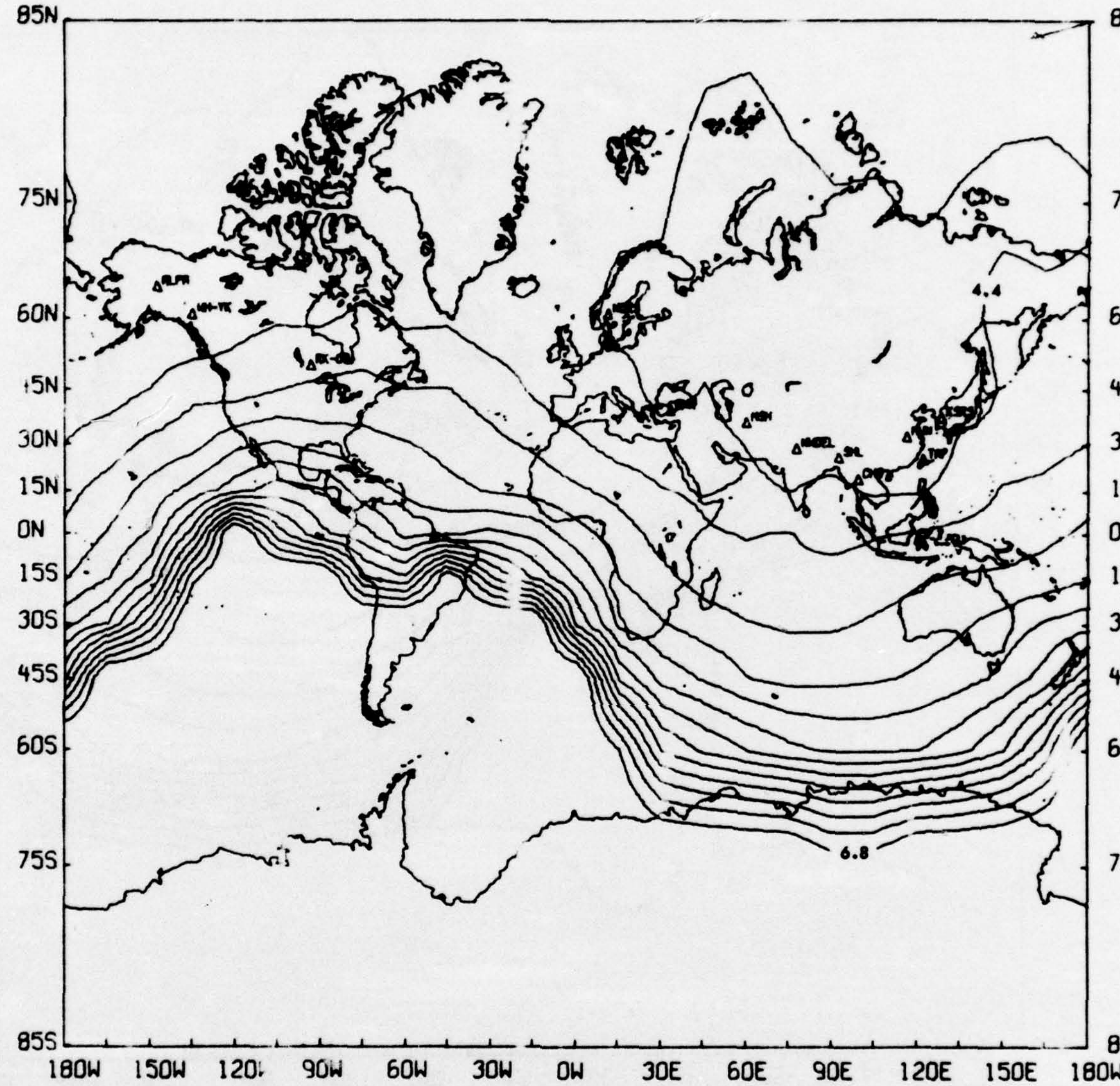

FIGURE A-2

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
LASA DELETED FROM NETWORK

TABLE A-2

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
NORSAR

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.855	4.84	4.53	.731	4.62	4.37	.816	4.47	4.34	.926	4.45	4.33	.664	4.41
15 E	4.71	.856	4.82	4.43	.636	4.50	4.38	.736	4.46	4.26	.999	4.39	4.33	.657	4.40
30 E	4.61	.793	4.72	4.43	.658	4.50	4.26	.911	4.37	4.29	.689	4.37	4.32	.678	4.39
45 E	4.57	.741	4.66	4.46	.698	4.53	4.34	.707	4.41	4.26	.711	4.34	4.27	.892	4.38
60 E	4.44	.609	4.52	4.39	.635	4.46	4.24	.486	4.29	4.26	.777	4.34	4.27	.871	4.37
75 E	4.40	.526	4.46	4.31	.518	4.37	4.30	.572	4.36	4.31	.514	4.35	4.30	.621	4.36
90 E	4.44	.528	4.50	4.32	.484	4.37	4.21	.451	4.25	4.31	.569	4.37	4.31	.492	4.36
105 E	4.37	.419	4.42	4.32	.449	4.37	4.23	.429	4.26	4.31	.574	4.37	4.31	.550	4.36
120 E	4.38	.353	4.42	4.23	.330	4.26	4.29	.451	4.33	4.28	.514	4.33	4.32	.574	4.38
135 E	4.44	.220	4.46	4.35	.405	4.39	4.25	.386	4.28	4.29	.449	4.34	4.30	.571	4.36
150 E	4.53	.071	4.54	4.35	.368	4.38	4.33	.435	4.37	4.34	.526	4.39	4.28	.553	4.35
165 E	4.53	.005	4.53	4.44	.385	4.48	4.38	.469	4.43	4.31	.487	4.37	4.28	.542	4.34
180 E	4.60	.001	4.60	4.48	.370	4.52	4.41	.480	4.45	4.32	.483	4.37	4.30	.549	4.35

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
ANK

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.835	4.83	4.53	.654	4.61	4.37	.772	4.47	4.34	.492	4.39	4.33	.574	4.39
15 E	4.71	.775	4.81	4.43	.851	4.53	4.38	.672	4.45	4.26	.798	4.37	4.33	.560	4.38
30 E	4.61	.883	4.74	4.43	.746	4.51	4.26	.861	4.37	4.29	.998	4.40	4.32	.546	4.37
45 E	4.57	.745	4.66	4.46	.728	4.53	4.34	.676	4.41	4.26	.863	4.36	4.27	.512	4.33
60 E	4.44	.648	4.53	4.39	.803	4.49	4.24	.874	4.34	4.26	.560	4.32	4.27	.515	4.32
75 E	4.40	.616	4.47	4.31	.542	4.37	4.30	.513	4.35	4.31	.536	4.36	4.30	.550	4.35
90 E	4.44	.599	4.51	4.32	.537	4.38	4.21	.474	4.25	4.31	.565	4.37	4.31	.551	4.36
105 E	4.37	.479	4.42	4.32	.483	4.37	4.23	.435	4.26	4.31	.529	4.36	4.31	.529	4.36
120 E	4.38	.429	4.43	4.23	.351	4.27	4.29	.437	4.33	4.28	.463	4.32	4.32	.519	4.37
135 E	4.44	.324	4.47	4.35	.398	4.39	4.25	.361	4.28	4.29	.437	4.33	4.30	.485	4.35
150 E	4.53	.021	4.53	4.35	.265	4.37	4.33	.385	4.36	4.34	.448	4.38	4.28	.451	4.33
165 E	4.53	.0	4.53	4.44	.065	4.44	4.38	.371	4.42	4.31	.399	4.35	4.28	.434	4.33
180 E	4.60	.0	4.60	4.48	.001	4.48	4.41	.270	4.43	4.32	.383	4.35	4.30	.434	4.34

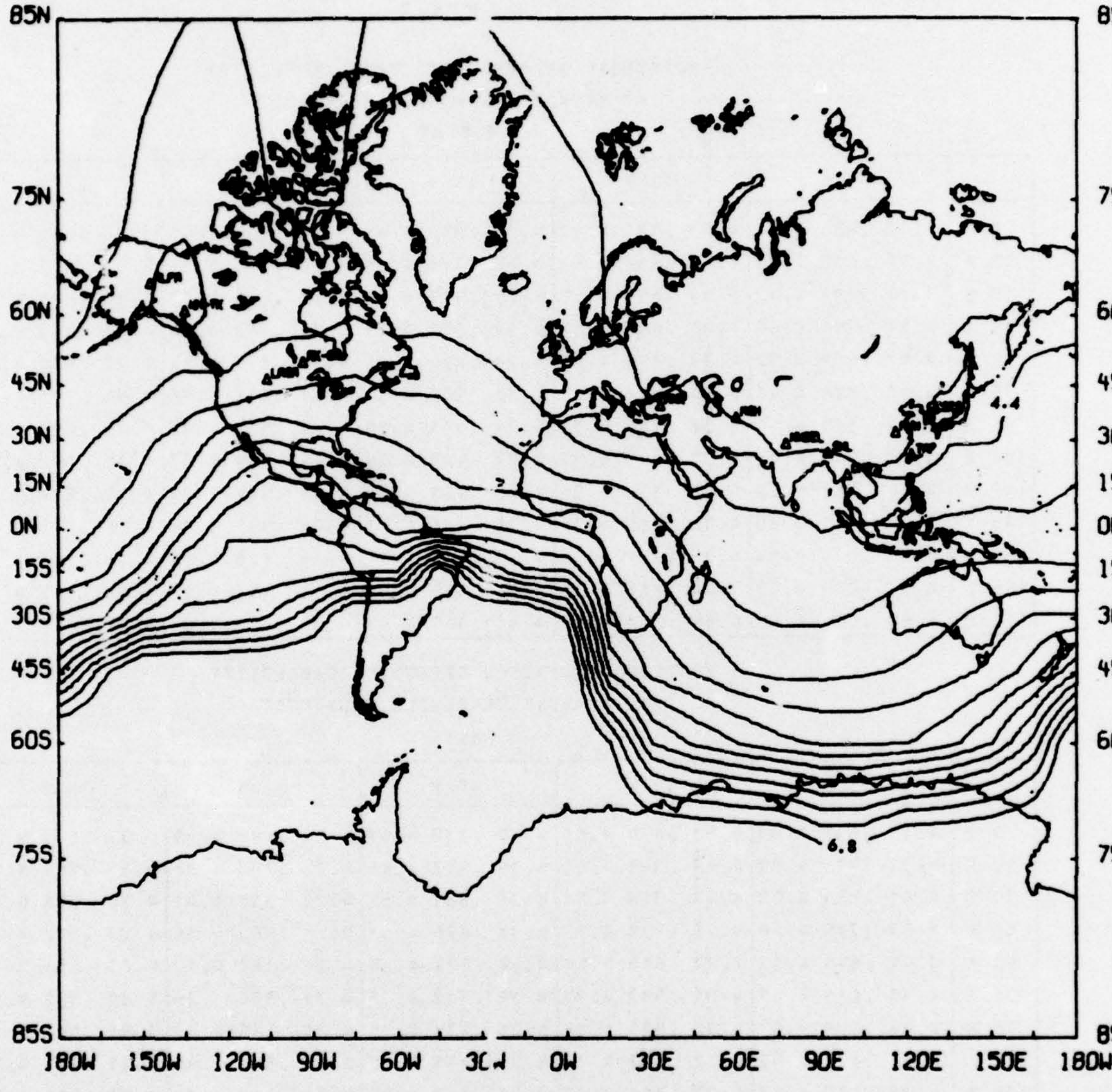

FIGURE A-3

THRESHOLD MAGNITUDE (m_b : 4.4 - 6.8):
NORSAR DELETED FROM NETWORK

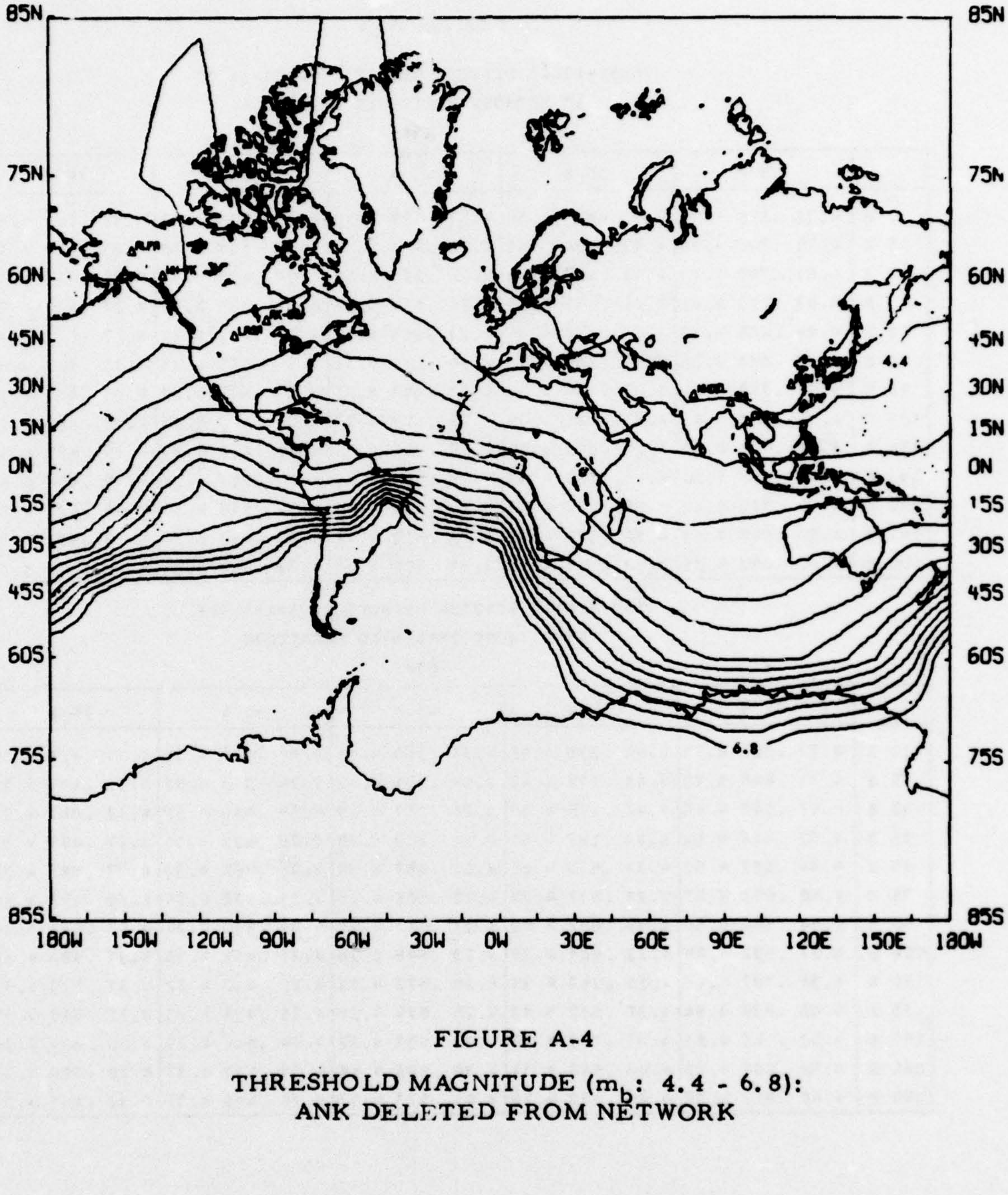

FIGURE A-4

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
ANK DELETED FROM NETWORK

TABLE A-3

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
CHG

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.375	4.75	4.53	.433	4.58	4.37	.387	4.41	4.34	.383	4.38	4.33	.402	4.37
15 E	4.71	.705	4.80	4.43	.484	4.48	4.38	.451	4.42	4.26	.351	4.30	4.33	.417	4.37
30 E	4.61	.700	4.71	4.43	.555	4.48	4.26	.399	4.30	4.29	.422	4.33	4.32	.428	4.36
45 E	4.57	.733	4.66	4.46	.651	4.52	4.34	.534	4.39	4.26	.433	4.30	4.27	.410	4.31
60 E	4.44	.675	4.53	4.39	.628	4.46	4.24	.505	4.29	4.26	.474	4.31	4.27	.423	4.31
75 E	4.40	.882	4.51	4.31	.758	4.41	4.30	.531	4.35	4.31	.551	4.36	4.30	.463	4.34
90 E	4.44	.799	4.54	4.32	.634	4.39	4.21	.443	4.25	4.31	.570	4.37	4.31	.481	4.36
105 E	4.37	.854	4.48	4.32	.646	4.39	4.23	.509	4.27	4.31	.570	4.37	4.31	.480	4.35
120 E	4.38	.945	4.51	4.23	.858	4.34	4.29	.501	4.33	4.28	.525	4.33	4.32	.485	4.37
135 E	4.44	.663	4.52	4.35	.583	4.41	4.25	.507	4.30	4.29	.507	4.34	4.30	.458	4.35
150 E	4.53	.720	4.62	4.35	.570	4.41	4.33	.538	4.38	4.34	.518	4.39	4.28	.423	4.33
165 E	4.53	.649	4.61	4.44	.578	4.50	4.38	.528	4.44	4.31	.452	4.36	4.28	.401	4.32
180 E	4.60	.632	4.69	4.48	.547	4.55	4.41	.488	4.46	4.32	.413	4.36	4.30	.392	4.33

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
MUN

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.006	4.71	4.53	.215	4.55	4.37	.350	4.41	4.34	.380	4.38	4.33	.424	4.38
15 E	4.71	.446	4.75	4.43	.414	4.47	4.38	.411	4.42	4.26	.345	4.30	4.33	.437	4.37
30 E	4.61	.597	4.69	4.43	.475	4.47	4.26	.357	4.29	4.29	.410	4.33	4.32	.447	4.36
45 E	4.57	.625	4.64	4.46	.563	4.51	4.34	.482	4.38	4.26	.422	4.30	4.27	.431	4.32
60 E	4.44	.587	4.52	4.39	.573	4.45	4.24	.457	4.29	4.26	.466	4.30	4.27	.447	4.31
75 E	4.40	.612	4.47	4.31	.513	4.37	4.30	.506	4.35	4.31	.532	4.36	4.30	.492	4.34
90 E	4.44	.554	4.50	4.32	.852	4.42	4.21	.673	4.28	4.31	.510	4.36	4.31	.517	4.36
105 E	4.37	.927	4.49	4.32	.661	4.39	4.23	.548	4.28	4.31	.434	4.35	4.31	.523	4.36
120 E	4.38	.797	4.49	4.23	.962	4.35	4.29	.572	4.34	4.28	.420	4.32	4.32	.535	4.37
135 E	4.44	.838	4.54	4.35	.692	4.42	4.25	.879	4.35	4.29	.454	4.33	4.30	.516	4.35
150 E	4.53	.703	4.61	4.35	.467	4.40	4.33	.452	4.37	4.34	.544	4.39	4.28	.487	4.34
165 E	4.53	.694	4.62	4.44	.645	4.51	4.38	.598	4.44	4.31	.532	4.37	4.28	.468	4.33
180 E	4.60	.685	4.70	4.48	.620	4.56	4.41	.571	4.47	4.32	.495	4.37	4.30	.461	4.34

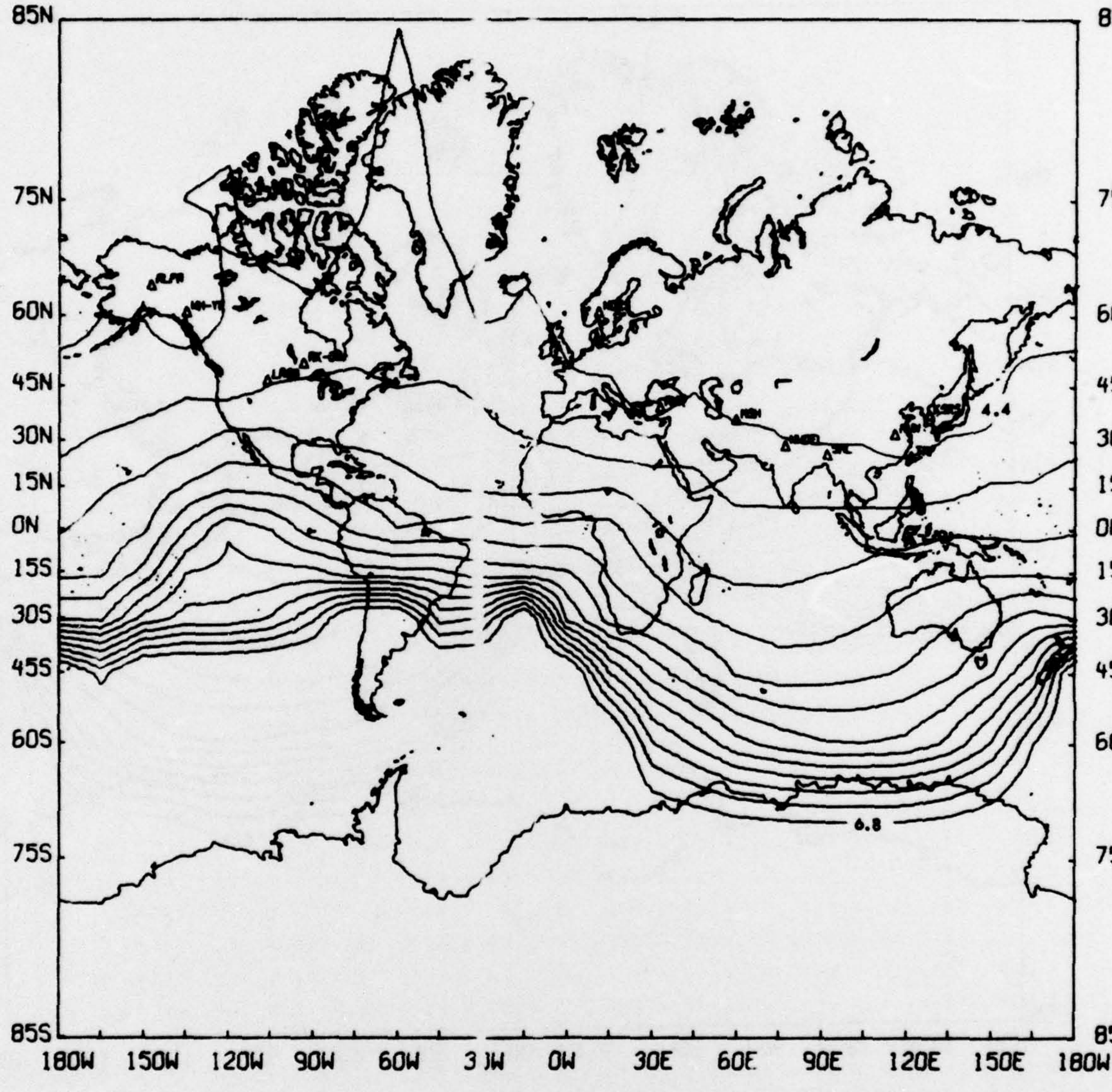

FIGURE A-5

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
CHG DELETED FROM NETWORK

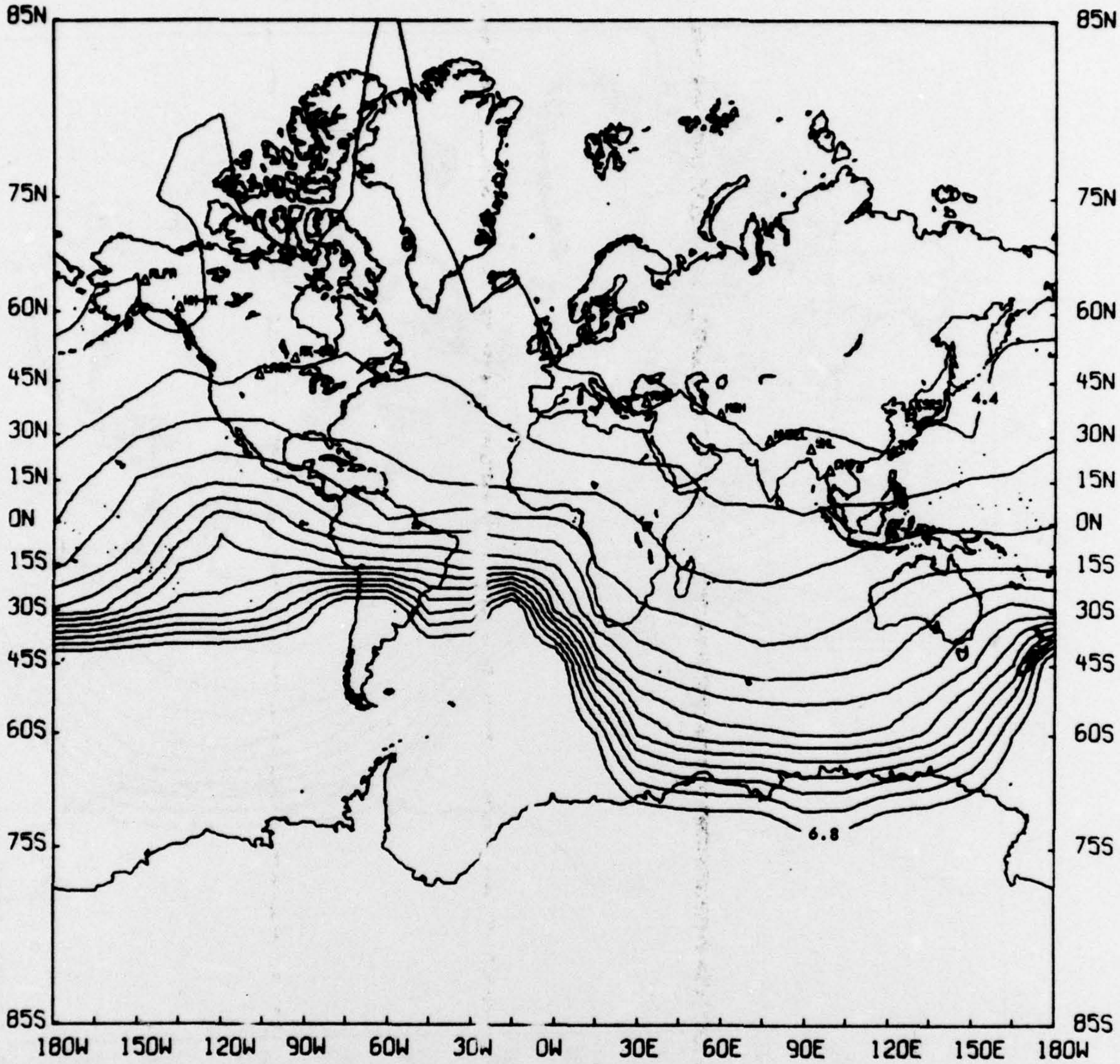

FIGURE A-6

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8)
MUN DELETED FROM NETWORK

TABLE A-4

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
KSRS

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.0	4.71	4.53	.052	4.54	4.37	.233	4.39	4.34	.282	4.37	4.33	.332	4.36
15 E	4.71	.068	4.71	4.43	.235	4.45	4.38	.293	4.40	4.2[illegible]	.248	4.28	4.33	.342	4.36
30 E	4.61	.390	4.66	4.43	.333	4.46	4.26	.243	4.28	4.29	.300	4.32	4.32	.349	4.35
45 E	4.57	.461	4.62	4.46	.409	4.49	4.34	.347	4.37	4.26	.309	4.28	4.27	.3[illegible]5	4.30
60 E	4.44	.419	4.49	4.39	.415	4.43	4.24	.322	4.27	4.26	.348	4.29	4.27	.350	4.30
75 E	4.40	.440	4.44	4.31	.405	4.35	4.30	.414	4.34	4.31	.422	4.35	4.30	.394	4.33
90 E	4.44	.536	4.50	4.32	.396	4.36	4.21	.252	4.23	4.31	.397	4.35	4.31	.421	4.35
105 E	4.37	.398	4.41	4.32	.845	4.42	4.23	.750	4.30	4.31	.421	4.35	4.31	.415	4.35
120 E	4.38	.751	4.48	4.23	.461	4.28	4.29	.527	4.34	4.28	.704	4.35	4.32	.420	4.36
135 E	4.44	.803	4.54	4.35	.586	4.41	4.25	.509	4.30	4.29	.720	4.36	4.30	.406	4.34
150 E	4.53	.526	4.59	4.35	.862	4.45	4.33	.750	4.41	4.34	.468	4.38	4.28	.394	4.32
165 E	4.53	.612	4.61	4.44	.493	4.49	4.38	.389	4.42	4.31	.394	4.35	4.28	.398	4.32
180 E	4.60	.621	4.69	4.48	.562	4.55	4.41	.500	4.46	4.32	.424	4.36	4.30	.392	4.33

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
MSH

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.616	4.79	4.53	.520	4.59	4.37	.422	4.42	4.34	.400	4.38	4.33	.383	4.37
15 E	4.71	.666	4.79	4.43	.474	4.48	4.38	.424	4.42	4.26	.344	4.29	4.33	.393	4.36
30 E	4.61	.595	4.69	4.43	.578	4.49	4.26	.560	4.32	4.29	.321	4.32	4.32	.397	4.35
45 E	4.57	.714	4.66	4.46	.550	4.51	4.34	.462	4.38	4.26	.447	4.30	4.27	.363	4.31
60 E	4.44	.827	4.56	4.39	.729	4.47	4.24	.483	4.29	4.26	.582	4.32	4.27	.358	4.30
75 E	4.40	.568	4.46	4.31	.442	4.36	4.30	.440	4.34	4.31	.475	4.36	4.30	.381	4.33
90 E	4.44	.471	4.49	4.32	.446	4.36	4.21	.483	4.25	4.31	.347	4.34	4.31	.393	4.35
105 E	4.37	.418	4.41	4.32	.395	4.36	4.23	.317	4.25	4.3	.384	4.35	4.31	.379	4.34
120 E	4.38	.373	4.42	4.23	.300	4.26	4.29	.357	4.32	4.28	.356	4.31	4.32	.372	4.35
135 E	4.44	.363	4.48	4.35	.333	4.38	4.25	.289	4.27	4.29	.330	4.32	4.30	.344	4.33
150 E	4.53	.373	4.57	4.35	.285	4.37	4.33	.301	4.35	4.34	.334	4.37	4.28	.314	4.31
165 E	4.53	.168	4.55	4.44	.292	4.46	4.38	.300	4.41	4.31	.288	4.34	4.28	.297	4.31
180 E	4.60	.002	4.60	4.48	.138	4.50	4.41	.283	4.43	4.32	.268	4.34	4.30	.293	4.32

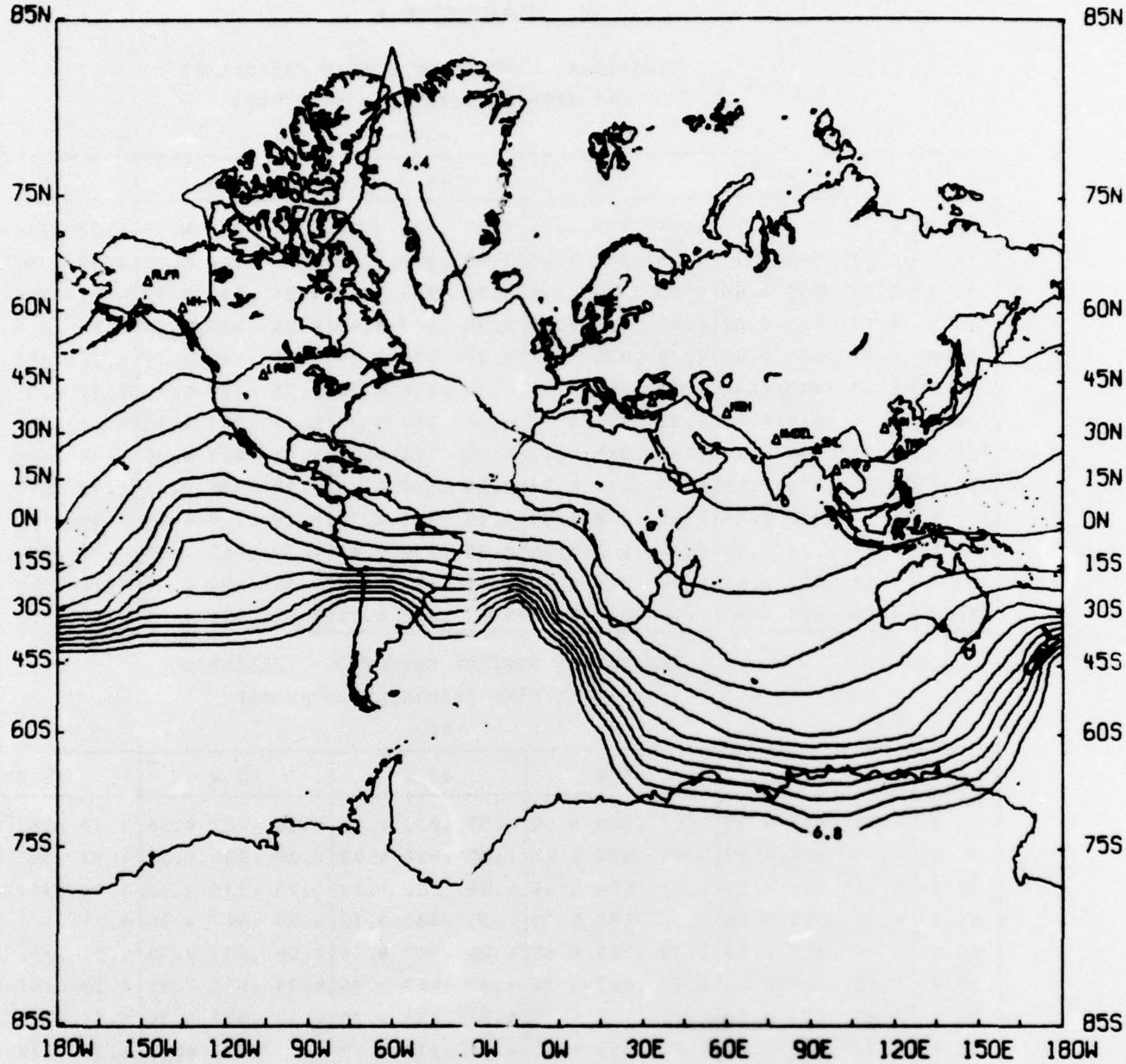

FIGURE A-7

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8): KSRS DELETED FROM NETWORK

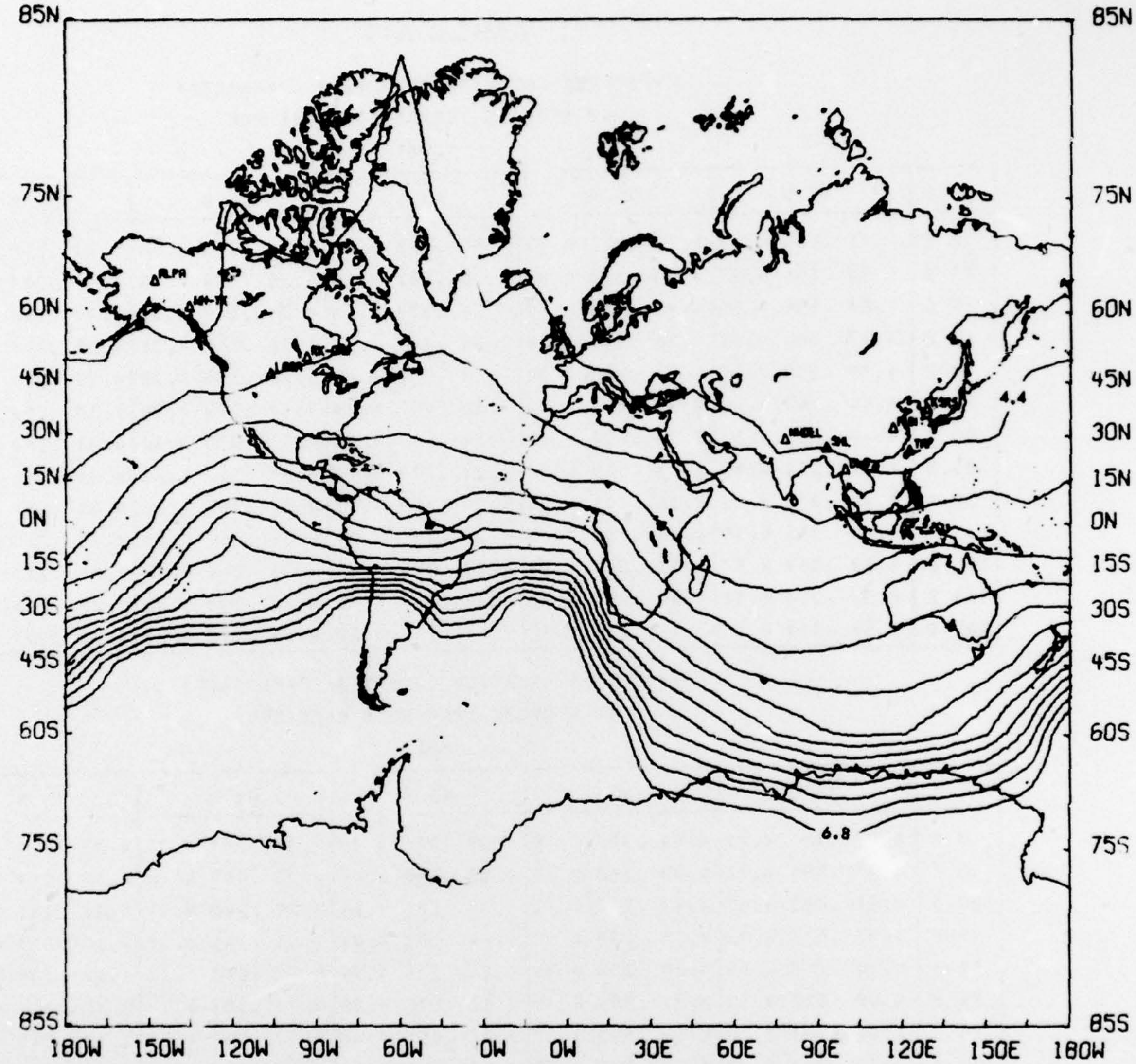

FIGURE A-8

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
MSH DELETED FROM NETWORK

TABLE A-5

INDIVIDUA STATION DETECTION CAPABILITY
AT N TWORK THRESHOLD MAGNITUDE
NWDEL

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.494	4.77	4.53	.372	4.57	4.37	.268	4.40	4.34	.253	4.36	4.33	.250	4.36
15 E	4.71	.564	4.77	4.43	.353	4.47	4.38	.322	4.41	4.26	.229	4.28	4.33	.262	4.35
30 E	4.61	.554	4.68	4.43	.418	4.47	4.26	.274	4.28	4.29	.284	4.32	4.32	.269	4.34
45 E	4.57	.506	4.62	4.46	.354	4.49	4.34	.268	4.36	4.26	.266	4.28	4.27	.251	4.30
60 E	4.44	.839	4.56	4.39	.448	4.44	4.24	.696	4.32	4.26	.254	4.28	4.27	.257	4.29
75 E	4.40	.443	4.44	4.31	.999	4.44	4.30	.440	4.34	4.31	.278	4.34	4.30	.282	4.32
90 E	4.44	.728	4.53	4.32	.402	4.36	4.21	.688	4.28	4.31	.510	4.34	4.31	.289	4.33
105 E	4.37	.273	4.40	4.32	.545	4.38	4.23	.219	4.24	4.31	.303	4.34	4.31	.280	4.33
120 E	4.38	.373	4.42	4.23	.245	4.25	4.29	.287	4.31	4.28	.285	4.30	4.32	.277	4.34
135 E	4.44	.355	4.48	4.35	.308	4.38	4.25	.239	4.27	4.29	.260	4.31	4.30	.250	4.33
150 E	4.53	.361	4.57	4.35	.247	4.37	4.33	.249	4.35	4.34	.264	4.36	4.28	.221	4.30
165 E	4.53	.298	4.56	4.44	.257	4.46	4.38	.243	4.40	4.31	.213	4.33	4.28	.203	4.30
180 E	4.60	.111	4.61	4.48	.211	4.50	4.41	.217	4.42	4.32	.188	4.33	4.30	.197	4.31

INDIVIDUA STATION DETECTION CAPABILITY
AT N TWORK THRESHOLD MAGNITUDE
SHL

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.393	4.75	4.53	.306	4.56	4.37	.216	4.39	4.34	.211	4.36	4.33	.221	4.35
15 E	4.71	.491	4.76	4.43	.288	4.46	4.38	.264	4.40	4.26	.189	4.28	4.33	.233	4.35
30 E	4.61	.483	4.67	4.43	.347	4.46	4.26	.224	4.28	4.29	.240	4.31	4.32	.241	4.34
45 E	4.57	.517	4.63	4.46	.438	4.50	4.34	.332	4.37	4.26	.249	4.28	4.27	.227	4.29
60 E	4.44	.389	4.49	4.39	.295	4.[illegible]2	4.24	.238	4.26	4.2[illegible]	.278	4.28	4.27	.235	4.29
75 E	4.40	.816	4.50	4.31	.393	4.35	4.30	.576	4.36	4.3[illegible]	.303	4.34	4.30	.264	4.32
90 E	4.44	.523	4.50	4.32	.825	4.[illegible]2	4.21	.691	4.28	4.3[illegible]	.297	4.34	4.31	.277	4.33
105 E	4.37	.481	4.42	4.32	.388	4.36	4.23	.645	4.29	4.31	.300	4.34	4.31	.273	4.33
120 E	4.38	.290	4.41	4.23	.380	4.27	4.29	.223	4.30	4.28	.287	4.30	4.32	.274	4.34
135 E	4.44	.426	4.49	4.35	.342	4.38	4.25	.265	4.27	4.2[illegible]	.280	4.31	4.30	.251	4.33
150 E	4.53	.430	4.58	4.35	.299	4.38	4.33	.287	4.35	4.34	.286	4.36	4.28	.223	4.30
165 E	4.53	.360	4.57	4.44	.307	4.47	4.38	.279	4.41	4.31	.233	4.33	4.28	.207	4.30
180 E	4.60	.348	4.64	4.48	.284	4.51	4.41	.249	4.43	4.32	.205	4.33	4.30	.200	4.31

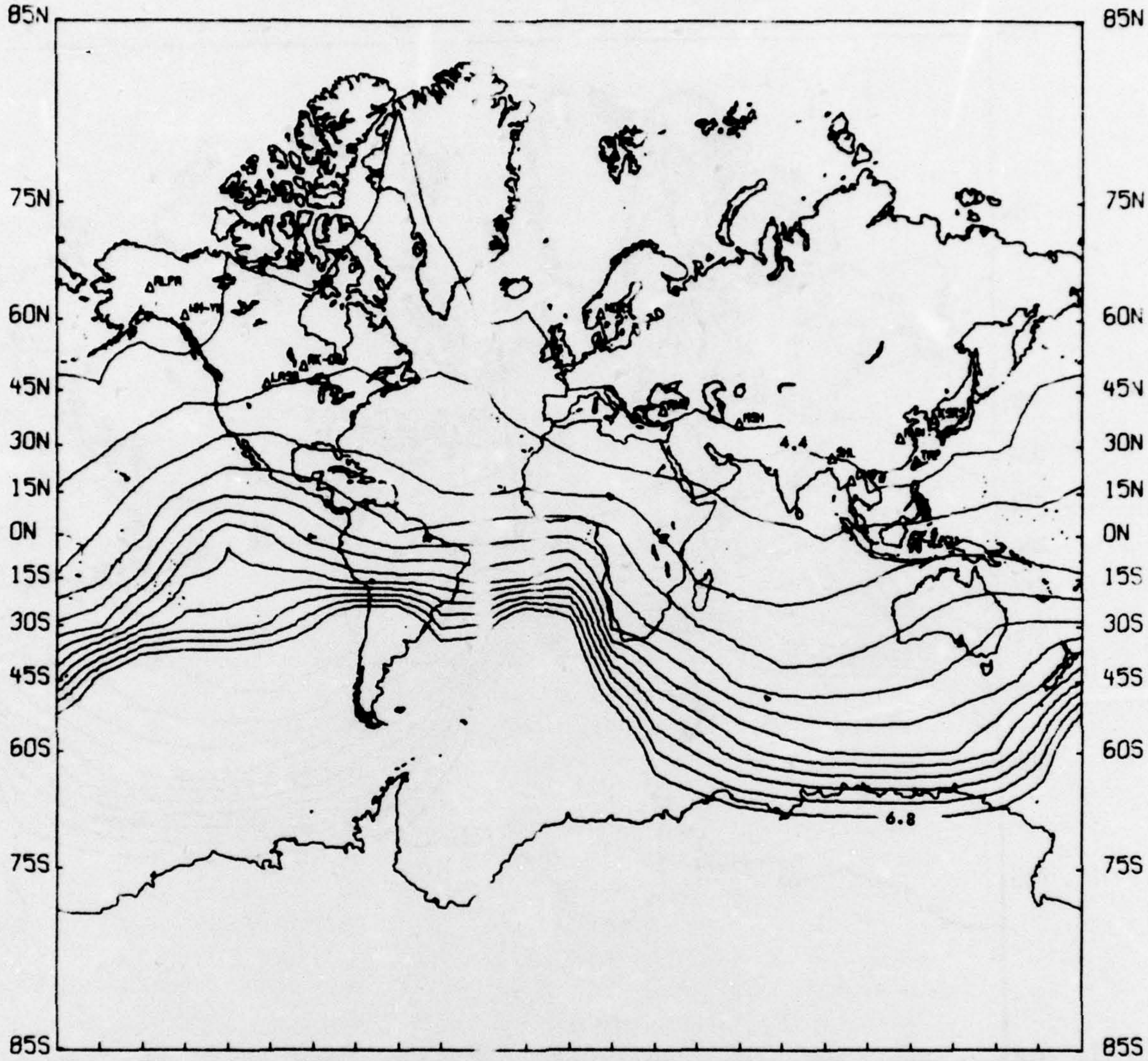

FIGURE A-9

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
NWDEL DELETED FROM NETWORK

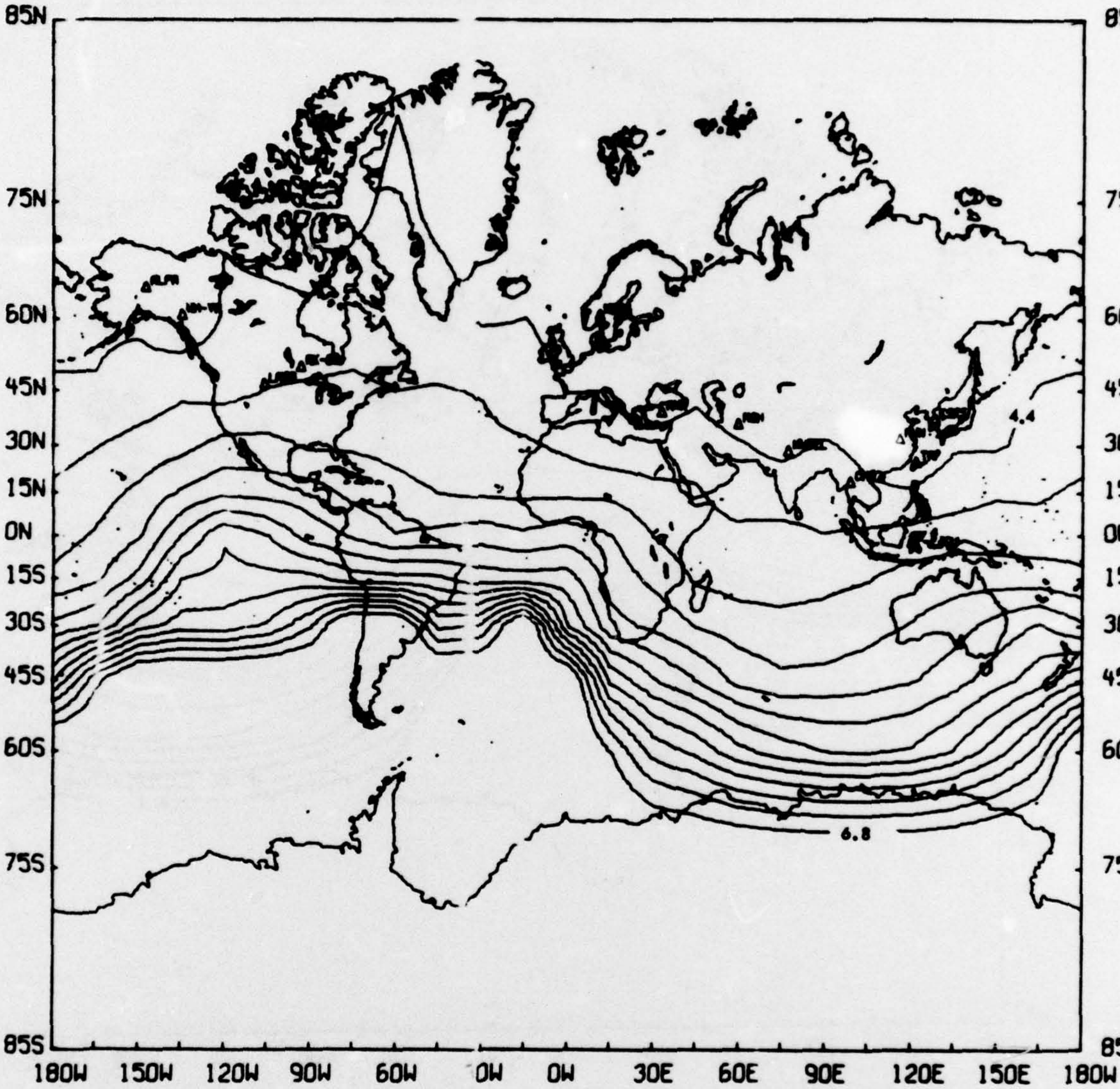

FIGURE A-10

THRESHOLD MAGNITUDE (m_b : 4.4 - 6.8):
SHL DELETED FROM NETWORK

TABLE A-6

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
WH-YK

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.125	4.72	4.53	.295	4.56	4.37	.258	4.40	4.34	.284	4.36	4.33	.326	4.36
15 E	4.71	.026	4.71	4.43	.211	4.[illegible]	4.38	.250	4.40	4.26	.234	4.28	4.33	.317	4.36
30 E	4.61	.005	4.61	4.43	.182	4.4	4.26	.188	4.27	4.29	.245	4.31	4.32	.306	4.34
45 E	4.57	.003	4.57	4.46	.179	4.47	4.34	.221	4.35	4.26	.227	4.28	4.27	.282	4.30
60 E	4.44	.002	4.44	4.39	.166	4.41	4.24	.183	4.26	4.26	.231	4.28	4.27	.281	4.29
75 E	4.40	.008	4.40	4.31	.159	4.3	4.30	.214	4.32	4.31	.261	4.33	4.30	.300	4.32
90 E	4.44	.059	4.45	4.32	.191	4.3	.21	.182	4.22	4.31	.271	4.34	4.31	.313	4.34
105 E	4.37	.130	4.38	4.32	.208	4.3	4.23	.201	4.24	4.31	.282	4.34	4.31	.308	4.33
120 E	4.38	.208	4.40	4.23	.184	4.2	4.29	.245	4.31	4.28	.279	4.30	4.32	.308	4.35
135 E	4.44	.266	4.47	4.35	.261	4.3	4.25	.246	4.27	4.29	.302	4.31	4.30	.291	4.33
150 E	4.53	.339	4.56	4.35	.282	4.3	4.33	.310	4.35	4.34	.317	4.37	4.28	.239	4.31
165 E	4.53	.366	4.57	4.44	.357	4.4	4.38	.348	4.41	4.31	.254	4.34	4.28	.387	4.32
180 E	4.60	.431	4.65	4.48	.410	4.5	4.41	.326	4.44	4.32	.604	4.38	4.30	.609	4.36

INDIVIDUAL STATION DETECTION CAPABILITY
AT NETWORK THRESHOLD MAGNITUDE
RK-ON

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.402	4.75	4.53	.340	4.56	4.37	.288	4.40	4.34	.300	4.37	4.33	.322	4.36
15 E	4.71	.292	4.73	4.43	.258	4.46	4.38	.267	4.40	4.26	.240	4.28	4.33	.306	4.35
30 E	4.61	.062	4.62	4.43	.218	4.45	4.26	.191	4.27	4.29	.240	4.31	4.32	.290	4.34
45 E	4.57	.0	4.57	4.46	.145	4.47	4.34	.212	4.35	4.26	.213	4.27	4.27	.260	4.30
60 E	4.44	.0	4.44	4.39	.053	4.40	4.24	.163	4.26	4.26	.207	4.28	4.27	.252	4.29
75 E	4.40	.0	4.40	4.31	.015	4.31	4.30	.175	4.32	4.31	.226	4.33	4.30	.264	4.32
90 E	4.44	.0	4.44	4.32	.011	4.32	4.21	.136	4.22	4.31	.226	4.33	4.31	.270	4.33
105 E	4.37	.0	4.37	4.32	.026	4.33	4.23	.152	4.24	4.31	.228	4.33	4.31	.270	4.33
120 E	4.38	.0	4.38	4.23	.052	4.24	4.29	.184	4.30	4.28	.219	4.30	4.32	.281	4.34
135 E	4.44	.006	4.44	4.35	.152	4.37	4.25	.180	4.26	4.29	.234	4.31	4.30	.279	4.33
150 E	4.53	.124	4.54	4.35	.207	4.37	4.33	.231	4.35	4.34	.273	4.36	4.28	.278	4.31
165 E	4.53	.268	4.56	4.44	.274	4.46	4.38	.281	4.41	4.31	.276	4.34	4.28	.287	4.31
180 E	4.60	.356	4.64	4.48	.328	4.52	4.41	.319	4.43	4.32	.299	4.34	4.30	.306	4.32

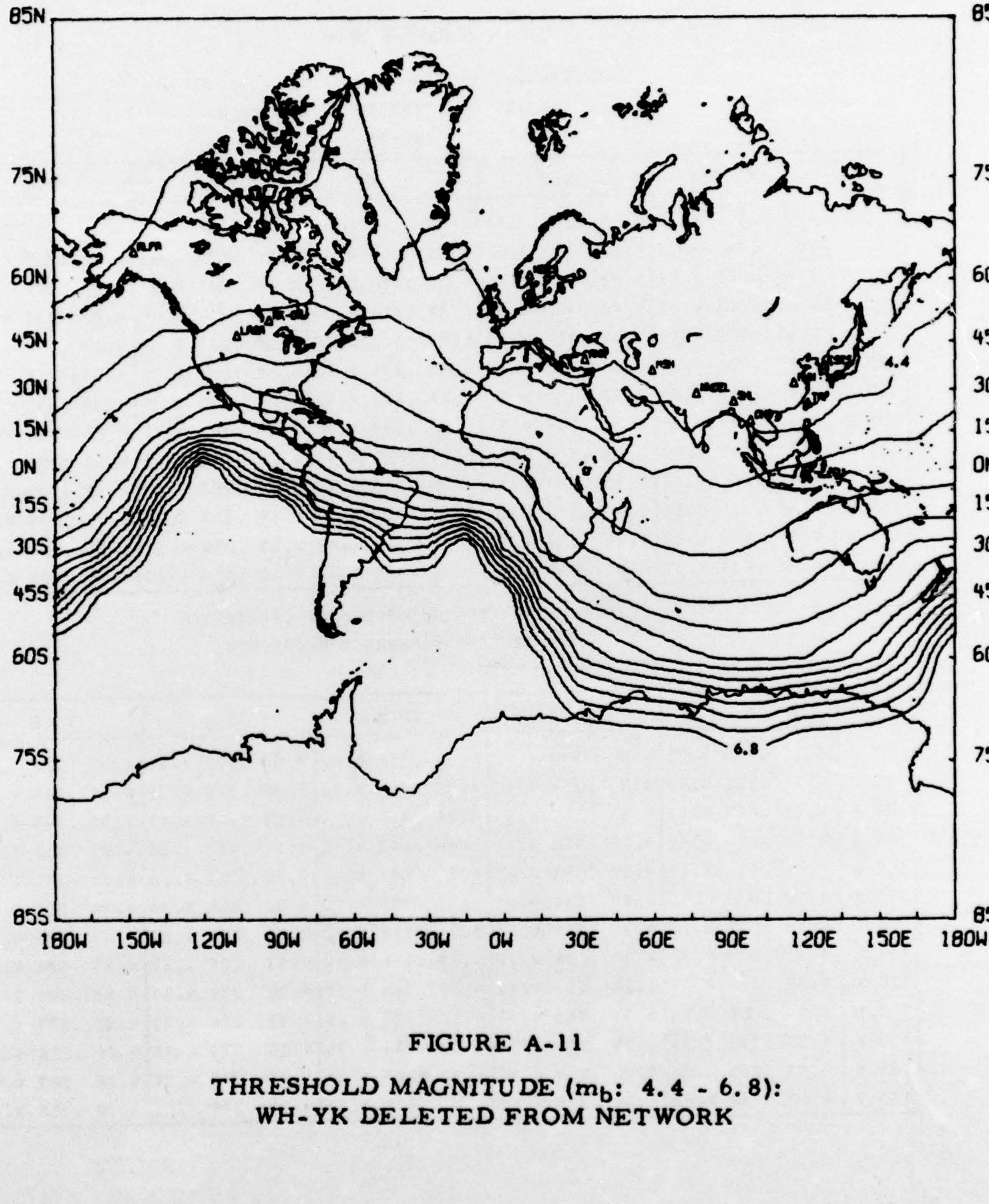

FIGURE A-11

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
WH-YK DELETED FROM NETWORK

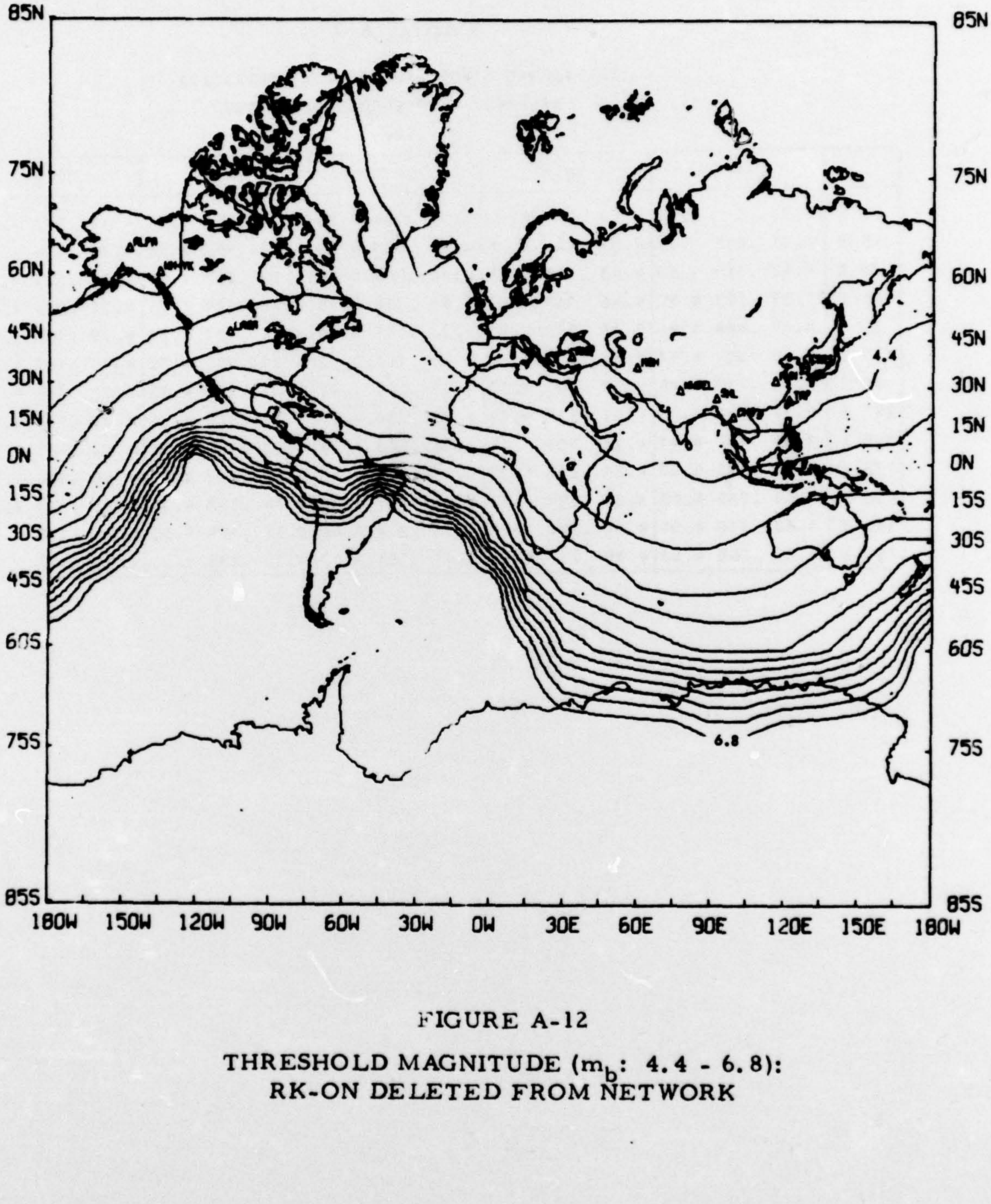

FIGURE A-12

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
RK-ON DELETED FROM NETWORK

TABLE A-7

INDIVIDUAL STATION DETECTION CAPABILITY

AT NETW'RK THRESHOLD MAGNITUDE

TAP

	15 N			30 N			45 N			60 N			75 N		
0 E	4.71	.0	4.71	4.53	.0	4.53	4.37	.024	4.38	4.34	.074	4.34	4.33	.091	4.34
15 E	4.71	.015	4.71	4.43	.044	4.44	4.38	.083	4.39	4.26	.062	4.26	4.33	.096	4.34
30 E	4.61	.169	4.63	4.43	.114	4.44	4.26	.066	4.26	4.29	.084	4.30	4.32	.100	4.32
45 E	4.57	.207	4.59	4.46	.161	4.47	4.34	.116	4.35	4.26	.089	4.26	4.27	.094	4.28
60 E	4.44	.184	4.46	4.39	.169	4.41	4.24	.105	4.25	4.26	.107	4.27	4.27	.100	4.28
75 E	4.40	.204	4.41	4.31	.167	4.32	4.30	.161	4.32	4.31	.150	4.32	4.30	.121	4.31
90 E	4.44	.212	4.46	4.32	.121	4.33	4.21	.104	4.22	4.31	.170	4.33	4.31	.133	4.32
105 E	4.37	.521	4.43	4.32	.229	4.34	4.23	.288	4.25	4.31	.160	4.32	4.31	.138	4.32
120 E	4.38	.290	4.41	4.23	.506	4.29	4.29	.563	4.34	4.28	.140	4.29	4.32	.145	4.33
135 E	4.44	.338	4.47	4.35	.230	4.37	4.25	.402	4.29	4.29	.147	4.30	4.30	.136	4.31
150 E	4.53	.235	4.55	4.35	.257	4.37	4.33	.137	4.34	4.34	.183	4.35	4.28	.123	4.29
165 E	4.53	.310	4.56	4.44	.240	4.46	4.38	.209	4.40	4.31	.154	4.33	4.28	.115	4.29
180 E	4.60	.298	4.63	4.48	.233	4.5[illegible]	4.41	.188	4.42	4.32	.135	4.33	4.30	.112	4.30

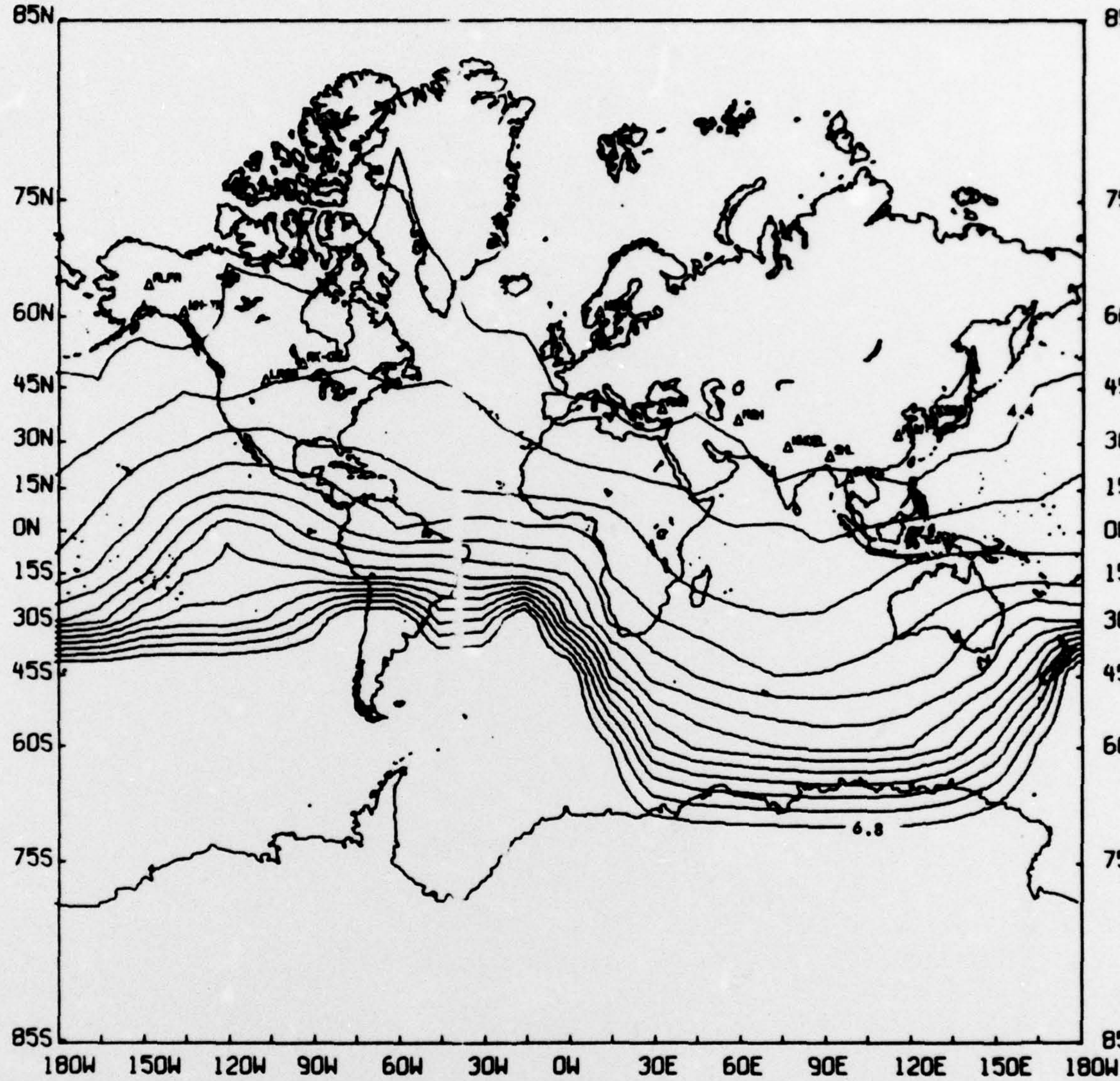

FIGURE A-13

THRESHOLD MAGNITUDE (m_b: 4.4 - 6.8):
TAP DELETED FROM NETWORK

APPENDIX B

NET 2

NET 2 is a NETWORTH computer program with the following modifications:

(1) The signal-to-noise ratio required for detection (SDT) and the signal variance (σ_s^2) may vary with station

(2) Amplitude bias corrections may be utilized for particular stations (all epicenters), particular epicenters (all stations), or particular station epicenter combinations

(3) The probability that each station is 'up' may be input, the station event detection probability becoming the probability that each station can detect the event if the station is 'up'.

These options require an additional control card following each station card, the data on this card being pertinent only to that station named on the preceding station card. The signal-to-noise ratio required for detection (SDT), the standard deviation of the signal (σ_s), and the station reliability are respectively input with format (3F10.0). Blanks in the field space designated for a particular variable, signal the use of a default. The defaults for the SDT and σ_s are those values input at the network level (NETWORTH control cards A and S). The default for the station reliability is 1.0; i.e., the station is considered always up. The addition of amplitude bias corrections involved correction of certain errors; the format of the appropriate control card is unchanged. Thus the control cards of NET 2 are the same as those of NETWORTH with the exception of one card (per station); if this card is left blank, NET 2 defaults to NETWORTH.