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VII. SUMMARY OF TECHNICAL REPORTS/PAPERS PREPARED

VII.1 Study of magnitudes, seismicity and earthquake detectability using a global network

The problem of bias in magnitudes estimated by a network of stations has been addressed in a number of investigations, e.g., Husebye et al (1974), Ringdal (1976), Evernden and Kohler (1976), Chinnery (1978), Christoffersson (1980), Elvers (1980) and Clark (1983). Most of these studies have concluded that the bias problem is indeed significant, especially at low magnitudes. The maximum-likelihood estimation technique described by Ringdal (1976) and Christoffersson (1980) has been shown to reduce the bias significantly. In this paper this method is adapted to a global network of the type reporting to the International Seismological Centre (ISC), and is applied to ten years of ISC data (1971-1980). The revised magnitudes thus obtained are compared to those obtained through conventional estimation techniques, and are also used to develop seismicity recurrence relations and to estimate network detection capability (Ringdal et al, 1977).

The basic model used in this paper has previously been described in detail by Ringdal (1976) and Christoffersson (1980). For further details, we refer to Ringdal (1984).

The data base for this study consisted of the ISC reportings for the 10-year period 1971-1980. At any given time in this period, a typical number of about 1000 seismic stations reported observations to the ISC. An investigation of the station reports confirmed the conclusions of North (1977), who analyzed similar data for the period 1964-1973. Thus, the large majority of stations contribute very few observations, in particular of log(A/T), and would thus be of little use in this study.

For the purpose of magnitude estimation, we found it desirable to select a sub-network of about 100 globally distributed stations. The following basic criteria were applied:

a) Consistent reporting, preferably over the entire 10-year period
b) High detectability, i.e., a large number of teleseismic reports

c) A sufficient number of log(A/T) reports to estimate station parameters
d) Adequate geographical distribution.

Clearly, these criteria were sometimes in conflict. For example, several very sensitive stations, e.g., the large LASA array and some VELA arrays, were only operational for part of the time period, but they were nevertheless selected. Also, the requirements were made less strict for stations in the southern hemisphere, in order to improve geographical coverage. Still, only a few useful stations could be found in Africa and South America. In the end, a total of 115 stations were selected. At any time during the 10 years, about 100 of these were in actual operation.

We note that some stations reported log(A/T) for a low proportion of their detections. It is clearly possible that their detection threshold thus is significantly lower than their threshold for reporting log(A/T). This possibility was investigated for each station by comparing the average ISC event m_b for the total set of reported detections with the average m_b for the subset for which log(A/T) was reported. As a first order approximation, we then adjusted the estimated thresholds according to the difference between these m_b values.

It should be observed that for some of the most sensitive stations, in particular some arrays, many of their reported detections are not associated with detected events in the ISC bulletin. Thus, the thresholds will be too high in these cases. In practice, this will make little difference in the maximum-likelihood procedure since non-detections by these stations for ISC-reported events are usually due to the stations being inoperative. For array stations, we also note that reportings by subarrays or associated stations in some cases replaced the full array reporting.

The previously described method and station network were applied to obtain maximum-likelihood m_b estimates for ISC-reported events during 1971-1980. Known and presumed explosions were removed from the data set so as not to bias the seismicity estimates. Furthermore, we restricted the data base to only those events which were reported by at least 4 stations of the 115 station network, and which had at least one detection in the distance range 21-100 degrees.

Since out network included most of the better stations reporting to the ISC, the resulting total of about 70 000 events comprised nearly all those events for which any teleseismic reports were included in the ISC bulletins. However, it should be noted that these bulletins also include a large number of events reported by local stations only.

Fig. VII.1.1 shows the resulting frequency-magnitude statistics for shallow events (depth < 60 km) globally. For comparison, similar statistics are also plotted using the magnitude estimation procedure currently employed by the ISC (i.e., averaging observed station magnitudes for all events with at least one log(A/T) report). The large difference in b-values (b=0.90 vs b=1.40) illustrates the statistical bias resulting from using conventional magnitude estimation.

Fig. VII.1.1 is quite similar to those obtained when comparing ISC magnitudes to magnitudes reported by sensitive array stations (Chinnery, 1978; Ringdal and Husebye, 1982). Average b-values obtained from array data for large epicentral regions are typically in the range 0.8-1.0, as demonstrated, e.g., for LASA, b ~ 0.84 (Dean, 1972), for NORSAR, b ~ .83 (Bungum and Husebye, 1974) and for the VELA arrays, b ~ 0.93 (Chinnery, 1978). Thus, the results using maximum-likelihood estimation are in good agreement with array studies. However, it must be realized that b-values can show significant regional variations (Evernden, 1970), and considerable caution in interpreting these data is therefore required.

Figs. VII.1.2 and VII.1.3 show incremental and cumulative statistics, respectively, averaged annually for shallow, intermediate and deep earthquakes. The slopes are approximately parallel, and the best-fitting cumulative relationships can be expressed as follows:

$\log_{10}(N_c) = 7.33 - 0.90\ m_b$ $\quad D \leq 60$ km

$\log_{10}(N_c) = 6.85 - 0.90\ m_b$ $\quad 60$ km $< D \leq 300$ km

$\log_{10}(N_c) = 6.13 - 0.90\ m_b$ $\quad D > 300$ km

Here, N_c denotes the cumulative number of earthquakes, and D denotes depth of focus as given by the ISC. Thus, about 70 per cent of global earthquakes are shallow, 25 per cent of intermediate depth and 5 per cent deep. The estimated average annual number of earthquakes globally is about 7500 above $m_b = 4.0$, and the number ranges between 6000 and 9000 for individual years within the ten-year period.

The distribution of estimated m_b bias values compared to conventional m_b estimation is illustrated in Figs. VII.1.4 and VII.1.5. In most cases, conventional m_b values are biased high by between 0 and 0.5 units. Fig. VII.1.5 shows that the bias problem is most significant at intermediate magnitudes. As expected, the bias values decrease somewhat when three or more station reports are required for m_b determination, but are even then significant.

At high magnitudes, our approach gives essentially the same m_b values as those of the ISC. Thus, we have not taken into account the possibility of bias introduced by clipping of strong signals at some stations for such events (Chinnery, 1978; von Seggern and Rivers, 1978). While this problem is important in many contexts, it would not significantly influence the seismicity statistics and detectability estimates in this study.

Based on the estimated magnitude data, an attempt was made to estimate the global teleseismic detectability of shallow events for the 115 station network. For this purpose a regional subdivision of the earth in grids of 15x15 degrees was made, and recurrence statistics for observed shallow earthquakes were considered within each grid area. The method of Kelly and Lacoss (1969) was then used to obtain detectability estimates for regions with sufficient number of observations, and approximate contours were drawn corresponding to these estimates.

Fig. VII.1.6 shows the results for 90 per cent incremental probability of detection at at least four stations. It is seen that the thresholds vary from better than $m_b = 4.2$ over much of the northern hemisphere to $m_b = 4.6$ or higher in parts of the southern hemisphere.

For comparison, the 'Networth' approach (Wirth, 1970) was also applied to the network. The results are shown in Fig. VII.1.7, and can be seen to be in good agreement with those of Fig. VII.1.6.

In some earlier studies, e.g., the report CCD/558, theoretical detection capabilities of global networks were found to be inconsistent with actually reported magnitude data. It would appear that this inconsistency has been largely due to the network magnitude bias problem inherent in conventional magnitude estimation techniques.

The thresholds estimated in this paper relate to average operating conditions of the global network. Under special circumstances, the actual thresholds might be different, e.g., the thresholds would be higher immediately after a large earthquake and during a major aftershock sequence. For this reason, the estimated seismicity levels must also be interpreted with some caution.

As expressed by Ringdal (1976), the maximum-likelihood procedure ideally requires actual measurements of threshold levels at all nondetecting stations for any given event. The statistical approach to thresholds and station downtimes used here has been chosen for practical reasons. However, it has been found by Ringdal (1976) and Christoffersson (1980) that even under very unfavorable circumstances, i.e., during a large aftershock sequence, the maximum-likelihood procedure, using estimated thresholds, produces acceptable results. Thus, while some individual events could be affected by occasional errors in the thresholds, the effect on the total earthquake statistics should be insignificant.

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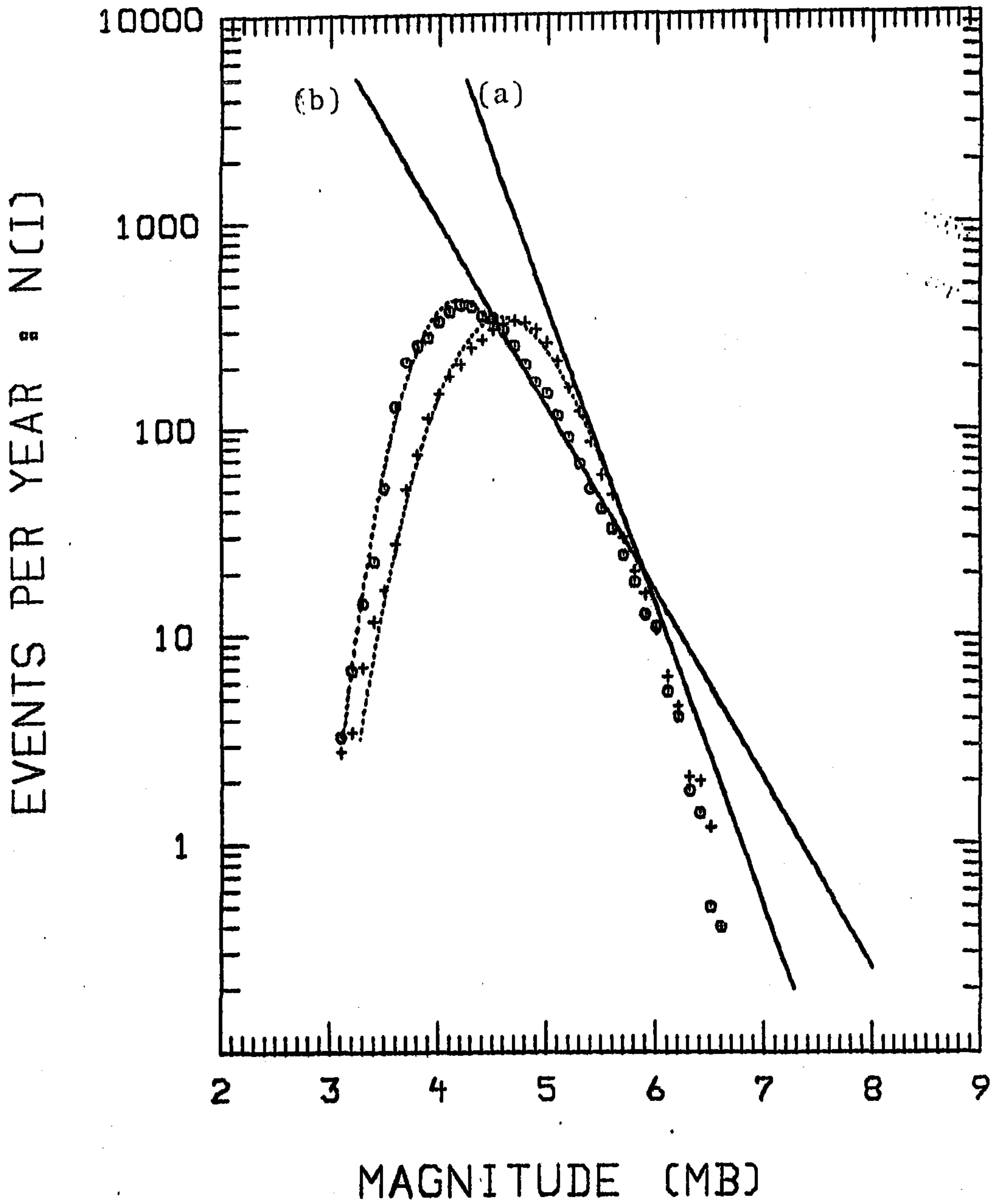

Fig. VII.1.1 Incremental recurrence statistics for shallow events (averaged per year), (a) using conventional m_b (one or more station observations) and (b) using maximum-likelihood m_b. The dotted lines indicate the fit of the Kelly-Lacoss (1969) model. Note the significant difference in slopes between the two cases.

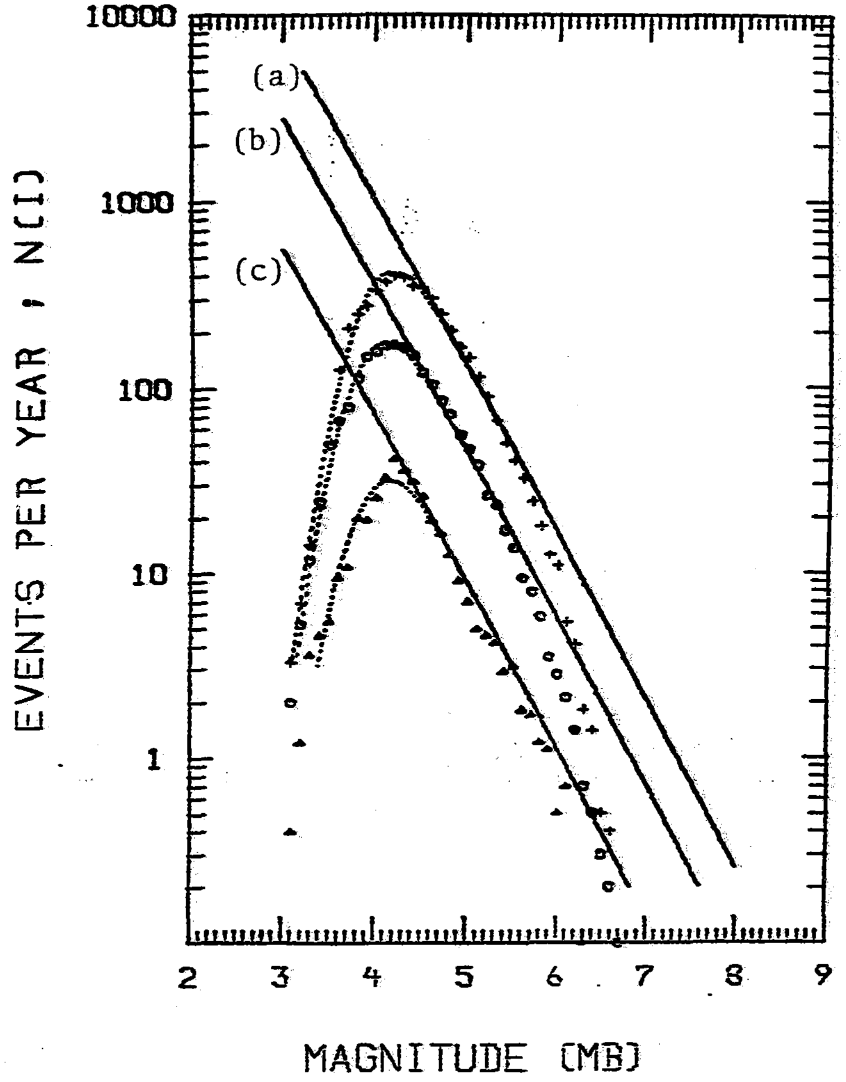

Fig. VII.1.2 Incremental recurrence statistics averaged annually for (a) shallow, (b) intermediate and (c) deep earthquakes globally, using maximum-likelihood m_b estimates

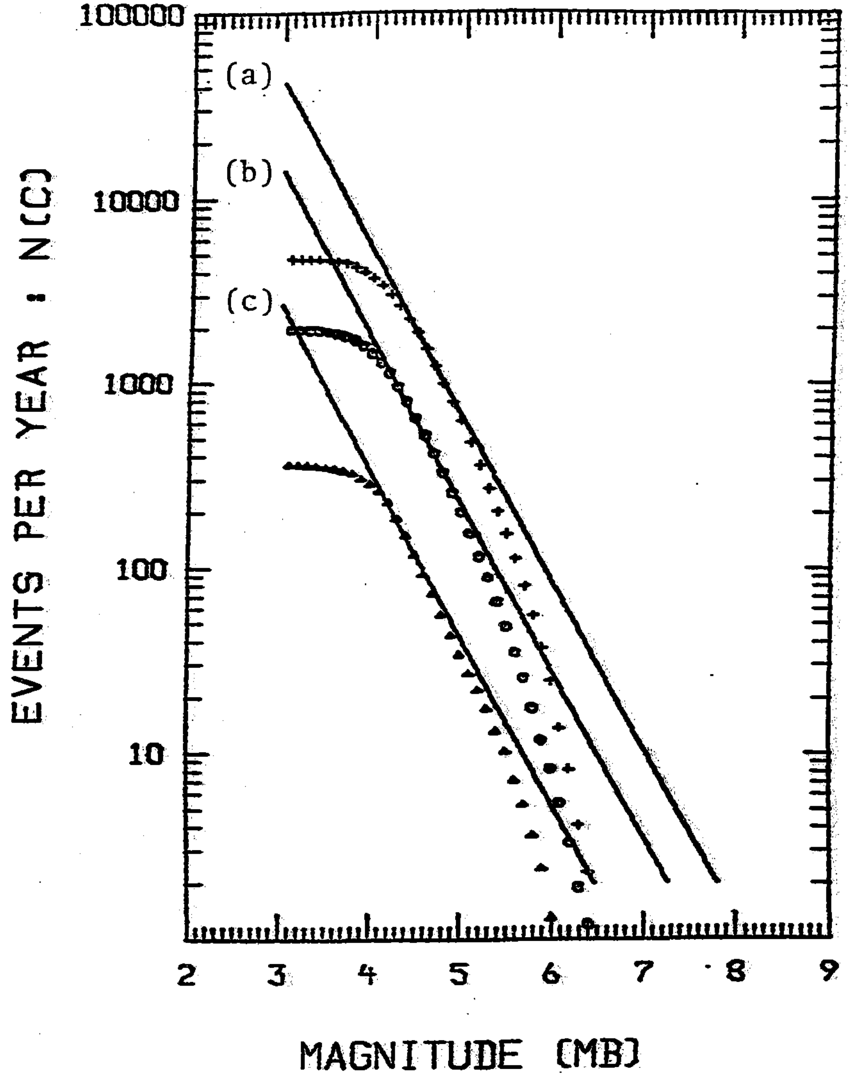

Fig. VII.1.3 Cumulative recurrence statistics averaged annually for (a) shallow, (b) intermediate and (c) deep earthquakes globally, using maximum-likelihood m_b estimates.

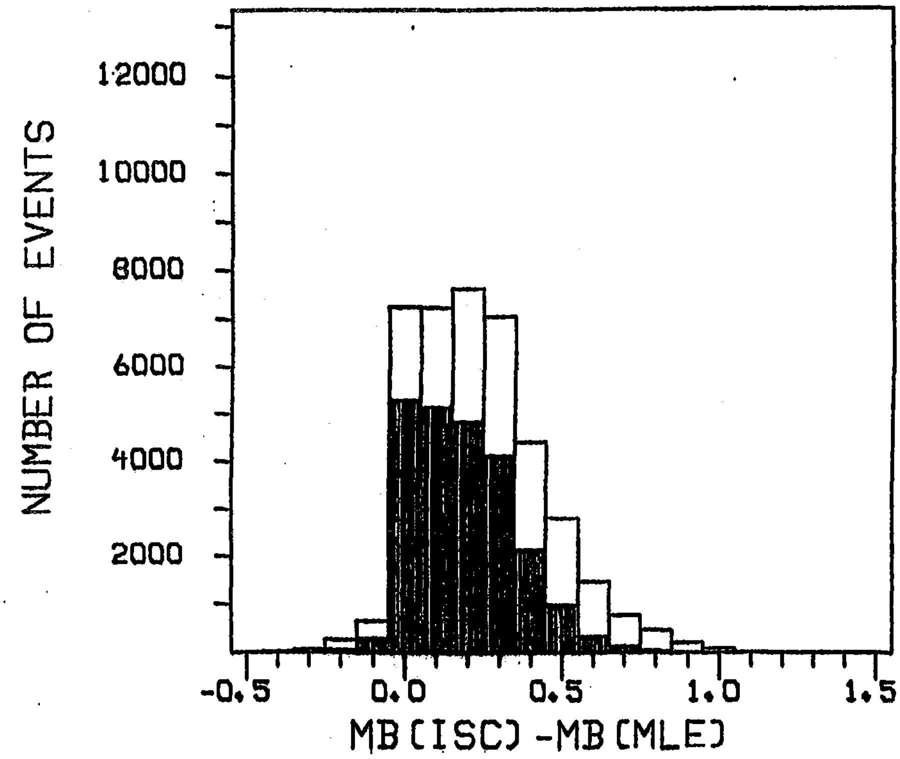

Fig. VII.1.4 Distribution of differences between conventional m_b and maximum-likelihood m_b. The filled columns correspond to requiring at least three observations in the conventional estimates.

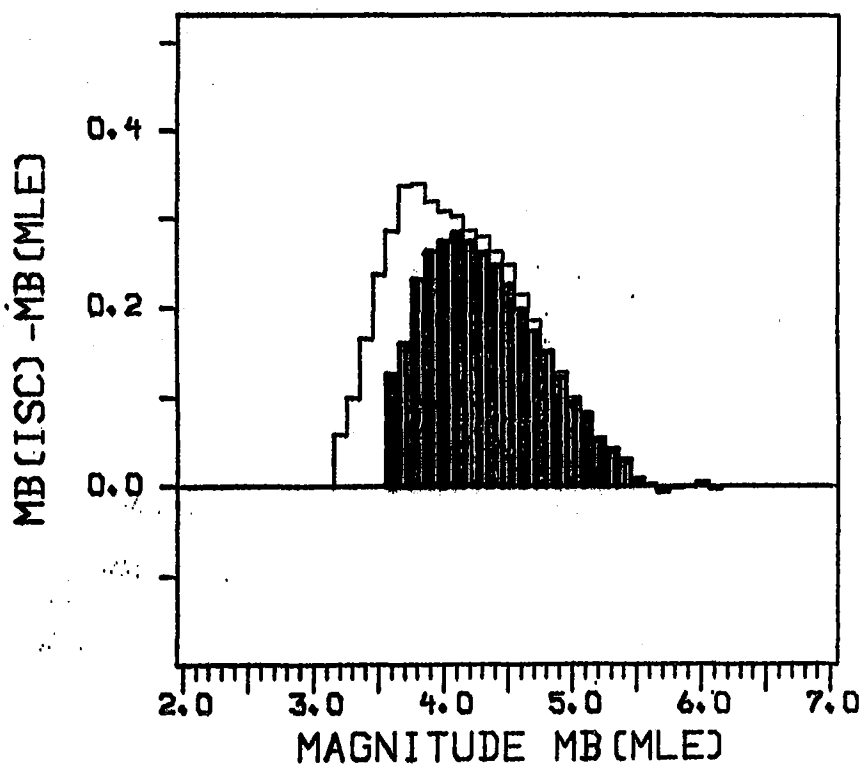

Fig. VII.1.5 Average m_b differences (as in Fig. VII.1.4) shown as a function of maximum-likelihood m_b. Note that the bias is most pronounced at intermediate magnitudes.

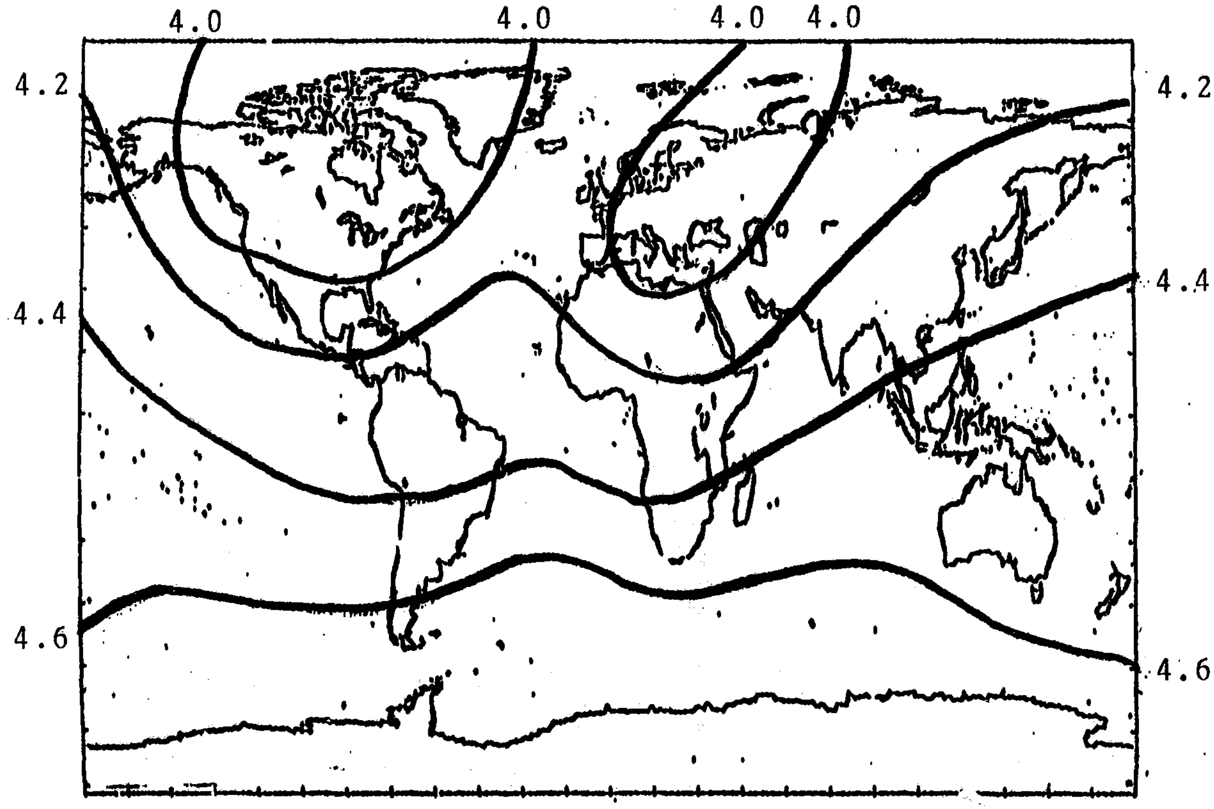

Fig. VII.1.6 Contours corresponding to 90 per cent incremental probability of detection at at least 4 stations of the network, requiring at least 1 teleseismic detection. This figure is based on observed recurrence statistics using maximum-likelihood m_b.

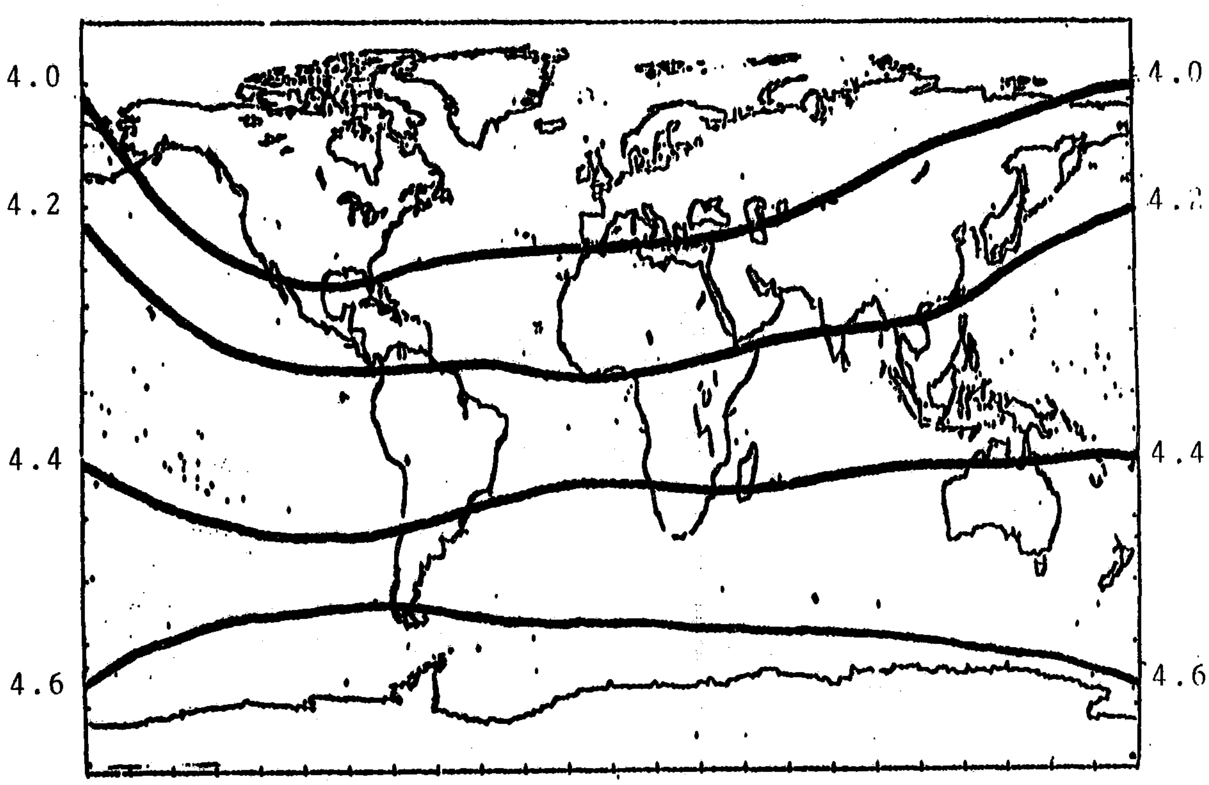

Fig. VII.1.7 Contours corresponding to 90 per cent incremental probability of detection at at least 4 stations of the network, using the 'Networth' approach.