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7.2 Regional detection and location performance during GSETT-2: Initial results for the Fennoscandian array network

Introduction

In this paper a preliminary assessment is made of the event detection and location capability during GSETT-2 for Fennoscandia and NW Russia. This is the region that had maybe the best instrumental coverage during the experiment. In particular the regional arrays deployed in this area made significant contributions.

Our results for this region represent in a sense the "best" regional performance during GSETT-2. It is in no way representative for the performance on a global or more extended regional scale. However, it does serve to illustrate the potential capabilities of a monitoring network, assuming that an adequate density and number of high quality, sensitive array stations are deployed.

This investigation is composed of three separate studies. Firstly, we describe the results of a detectability study, where the reference data base is the seismic bulletin published by the University of Helsinki, Finland. The second study is also on detectability, and here the reference data base is the bulletin published by the University of Bergen, Norway. The third part of the investigation is a study on event location performance, where event locations in the FEBs are compared with locations published in the Helsinki bulletin.

Detectability study: Comparisons with the bulletin of the University of Helsinki

Method

The method used for detectability estimation has been described by Ringdal (1975):

- A reference system, independent of the system to be evaluated, is used. Event lists and magnitudes from this reference system are compiled.
- For each reference event, a comparison is made to see if the system to be evaluated has detected the event.
- Based on the number of detections/no detections at each magnitude, a maximum likelihood "detection curve" is estimated.

Reference network

The reference data base for this study has been the catalogue of seismic events in northern Europe regularly compiled by the Seismological Institute, University of Helsinki.

The stations used in compiling this catalogue are in almost all cases comprised on the Finnish seismic network single stations. For all practical purposes, the compilation is independent of the regional arrays in Fennoscandia (NORESS, ARCESS, FINESA). The magnitudes quoted in the bulletin are likewise derived independently of the regional arrays, and comprise either duration magnitudes (in most cases) or local magnitudes.

These magnitudes are fairly consistent with magnitudes calculated by the Intelligent Monitoring System, while their relationship to teleseismic m_b estimates is at present not well established.

For the month of May 1991, upon which this analysis is based, the reference catalogue contained 321 seismic events in the region bounded by 58^o-70^oN, 20^o-40^oE, of which 108 had an assigned magnitude in the range 1.7-2.9.

Results

The initial results from the detectability study are summarized in Figs. 7.2.1-7.2.2 (see also Ringdal, 1991). The figures are based upon analyst comparison of the reference events with bulletin reports according to the criteria:

a) **NDC-reported event:**

In Fig. 7.2.1, an event is considered detected if it was reported with 2 phases (P and S; or P and Lg) by at least one of the three regional arrays (NORESS, ARCESS, FINESA). In terms of GSETT-2 final event bulletins, this means that the event was either located as a multi-station event, or listed as an NDC-reported event. We note that the 50% threshold is close to 1.7, and the 90% threshold is 2.3 in this case.

b) **FEB-reported events**:

In Fig. 7.2.2, the FEB-reported events, located by at least one IDC, are shown. (We have not counted as detected events those events whose definition depended upon reportings from the Finnish network stations KAF and VAF, since these two stations were part of the reference network.) This added requirement has the effect of increasing the 50% threshold to 2.1, and the 90% threshold to 2.4.

Detectability study: Comparisons with the bulletin of the University of Bergen

Reference network

The seismic bulletin published by the Institute of Solid Earth Physics of the University of Bergen, Norway, has been the reference data base for this study.

The stations used by the University of Bergen in compiling their bulletin are shown in Fig. 7.2.3. The events reported in this bulletin are basically confined to southwestern and northern Norway, the North Sea and the continental margin to the west of Norway. This bulletin thus very suitably supplements the Helsinki bulletin with respect to coverage of Fennoscandian seismic events.

Detections from NORESS and ARCESS are to a certain extent used in compilation of the University of Bergen bulletin. However, only events that were reported without use of NORESS/ARCESS readings, or that would have been reported even if NORESS/ ARCESS data were not used (i.e., events for which the University of Bergen network alone had a sufficient number of phases), were used as reference events. The magnitudes given in the University of Bergen bulletin are duration magnitudes. These magnitude values are generally higher than those calculated by the Intelligent Monitoring System (typically by 0.5 magnitude units).

For the GSETT-2 period, 22 April - 2 June 1991, the University of Bergen bulletin contains 83 events satisfying the criteria mentioned above (a couple of small events very close to the JMI network are excluded from consideration). The coda magnitudes are in the range 0.3-4.0.

Results

For each of the 83 events in the reference data base, we checked whether or not the event was reported during GSETT-2 by the Norwegian NDC. Such reports of local/regional events always included a FOCUS line, and the event origin time and geographical coordinates were based on at least one P- and one S-phase from either NORESS or ARCESS. The results from this study are presented in Fig. 7.2.4, where the detectability curve has been computed in accordance with the method outlined above.

We can see from Fig. 7.2.4 that the 50% threshold is close to 1.5, and that the 90% threshold is a little less than 2.5. These results should be compared to those in Fig. 7.2.1, which were obtained for the same reporting criterion (two phases on at least one array). Taking into account that the University of Bergen magnitudes are slightly higher than those reported by IMS and the University of Helsinki, it appears that 90% event detection probability of the Fennoscandian regional array network is at magnitude 2.5 or lower across the entire Fennoscandia from the Norwegian continental shelf to northwestern Russia.

It should be noted that for three events counted as detected events in Fig. 7.2.4, only a single P phase was reported by the Norwegian NDC during GSETT-2. For one of these events, an Sn phase was also automatically detected, but by mistake not reported during GSETT-2. For the other two events, there were no automatic S-phase detections, but inspection of the associated waveforms reveals the presence of a regional event that could and would have been reported as such given more time and resources during the NDC analysis stage.

Event location performance: Comparison between the FEBs and the University of Helsinki bulletin

Data base

To evaluate the regional event location performance for Fennoscandia and northwestern Russia, we again selected as a reference data base the bulletin published by the Institute of Seismology of the University of Helsinki. For the GSETT-2 test period 22 April - 2 June 1991, altogether 430 local and regional events were reported in the Helsinki bulletins, and 257 of these events were also found in the "IDC section" of the corresponding FEBs. (Two different solutions were given for two of these events, thus resulting in a total of 259 events in the FEB data base.)

It must be noted that the two data bases are not entirely independent relative to each other: The FEB events located in Finland were generally composed of reported or added readings from the stations KAF, VAF (part of the reference network) and the FINESA array. However, this interdependence does not represent a problem in the study on event location performance reported on here.

The 257 reference events comprised six earthquakes, one in central Finland, one in the Svalbard region, and four in the North Sea/Norwegian Sea, while the remaining events were presumed regional explosions of low magnitude. Fig. 7.2.5 shows the epicenters of the events, together with the stations of the Finnish Seismograph Network.

Due to the relatively high mining activity in the region, a normal practice in producing the Helsinki bulletin is to apply a brief reporting, i.e., manually determined source information with no phase readings, to events from the known sites. However, epicenters for the events reported by the Finnish NDC during GSETT-2 were determined using an iterative location procedure.

According to the estimated location accuracy, the reference events were divided into five groups:

Group I

Nineteen quarry blasts from seven Finnish mines or quarries. The blasts were confirmed by the responsible authorities, and the location was reported with an accuracy of better than $\pm$ 500 m. In the Helsinki bulletin, the complete location procedure was applied for 14 of these events, and a true location accuracy of 4.2 $\pm$ 3 km was calculated for this group.

Group II

Events located in the area where the coverage of the reference network is good (approximately 60^o-66^oN and 22^o-29^oE). The average station-to-epicenter distance is 150 km. As the events in group I also belong to this group, a reasonable estimate for the location accuracy is $\pm$ 5 km.

Group III

Events located at the edges of the Finnish network, including the coast of Estonia. The average epicentral distance is 250 km. Events from the known mines in northern Sweden and northwestern Russia -- reported with manually determined epicenters in the Helsinki bulletin -- are also included in this group. The accuracy of the Helsinki bulletin location is estimated to be $\pm$ 10 km.

Group IV

Events in northern Fennoscandia, northwestern Russia and the Baltic Sea, the average epicentral distance being 450 km. Estimated accuracy of the location in the Helsinki bulletin is $\pm$ 15 km.

Group V

Five earthquakes off continental Fennoscandia, in the Norwegian Sea and the North Sea. The events are far from the reference network, the average distance being 1000 km. However, as these event reports contain also readings from other seismological institutes in the region (13-30 stations were used in the epicenter determination), a reasonable estimate for the location accuracy is ± 20 km.

Results from the FEB analysis

Table 7.2.1 shows the number of FEB events in each of the five groups versus the EIDC responsible for the representative solution. In Table 7.2.1 it is noteworthy that 61 per cent of the representative solutions for Fennoscandian events originated from the WAS EIDC. The median value plus 25% and 75% quadratiles (Q) for differences between the FEB solution and the true location (group I) or the reference location (groups II-V) are also given in Table 7.2.1.

Group	**CNB**	**MOS**	**STO**	**WAS**	**Total**	**Median** (km)	**25% Q** (km)	**75% Q** (km)
I	6	-	-	13	19	10.2	6.2	22.6
II	10	-	3	40	53	13.6	8.1	24.3
III	45	6	23	91	165	29.0	15.1	49.3
IV	-	-	4	13	17	36.6	17.7	53.7
V	1	-	2	2	5	42.5	27.5	87.7
Total	62	6	32	159	259			

Table 7.2.1. Location statistics for the regional events.

From Table 7.2.1 we make the following observations:

Group I events:

The median FEB location error (relative to true location) is 10.2 km. This can be compared to a true location error of 4.2 km obtained by using Finnish network data.

Group II events:

Here, the reference locations are estimated to be accurate to ± 5 km. The median FEB location "error" relative to these estimates is 13.6 km. Thus the FEB performance is similar to Group I events. (Estimate of "absolute" error is $\sqrt{13.6^2 - 5^2}$ km = 12.6 km.)

Group III events:

Here, the reference locations are estimated to be accurate to $\pm$ 10 km. The median FEB location "error" is 29.0 km. An estimate of "absolute" error is $\sqrt{29^2 - 10^2}$ km = 27.2 km. Thus Group III events have clearly inferior location accuracy compared to Groups I and II.

Group IV events:

Here, the reference locations are estimated to be accurate to $\pm$ 15 km. The median FEB location "error" relative to these estimates is 36.6 km. An estimate of the "absolute" error is $\sqrt{36.6^2 - 15^2}$ km = 33.4 km. This is slightly higher than for Group III.

Group V events:

Here, the number of events is too low to compute any meaningful statistics, but the FEB performance seems to be not very different from Group IV events.

A closer inspection of the FEBs shows that the location accuracy varied considerably between different EIDCs. The scatter can partly be explained by the different degree of experience with the analysis of data from this region. For example, some EIDCs did not place any constraints on the event depth in the location procedure for many of the events dealt with here.

Part of the location differences are due to the different velocity models used in the Helsinki bulletin and at the EIDCs. To illustrate this, we have plotted in Fig. 7.2.6 the difference in epicentral distance derived from the WAS EIDC standard travel-time tables and the Helsinki velocity model used in the Helsinki bulletin. As can be seen from the figure, differences up to 11 km exist at the regional distance range. The differences may be even greater in case other velocity models are applied.

Conclusions

The regional evaluation of detection results from GSETT-2 presented here shows that in a region with dense coverage of high-quality array stations as in Fennoscandia, it is possible to detect seismic events at very low magnitudes.

The 90 per cent threshold of around magnitude 2.5 found in this study for different parts of Fennoscandia must of course be considered with the appropriate caution: Thus it refers to regional magnitude scales that currently are not well calibrated in terms of global magnitude. Also, in other geological environments, the wave propagation and array noise suppression characteristics may be different. Therefore, it is not known to which extent such results would be possible to duplicate in other parts of the world.

Evaluation of the regional event location performance in Fennoscandia showed that in an area where the coverage of the GSETT-2 network is good, the location accuracy approaches that obtained by national networks.

There are indications that the location errors may be reduced by using regional velocity models. In addition, knowledge on the characteristics of seismicity in the region would further improve the results.

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References

Ringdal, F. (1975): On the estimation of seismic detection thresholds, *Bull. Seism. Soc. Am.*, 65, 1631-1642.

Ringdal, F. (1991): Regional detection performance during GSETT-2: Initial results for the Fennoscandian array network. Semiann. Tech. Summ., 1Mar - 30 Sep 1991, NORSAR Sci. Rep. 1-91/92, Nov 91, NORSAR, Kjeller, Norway.

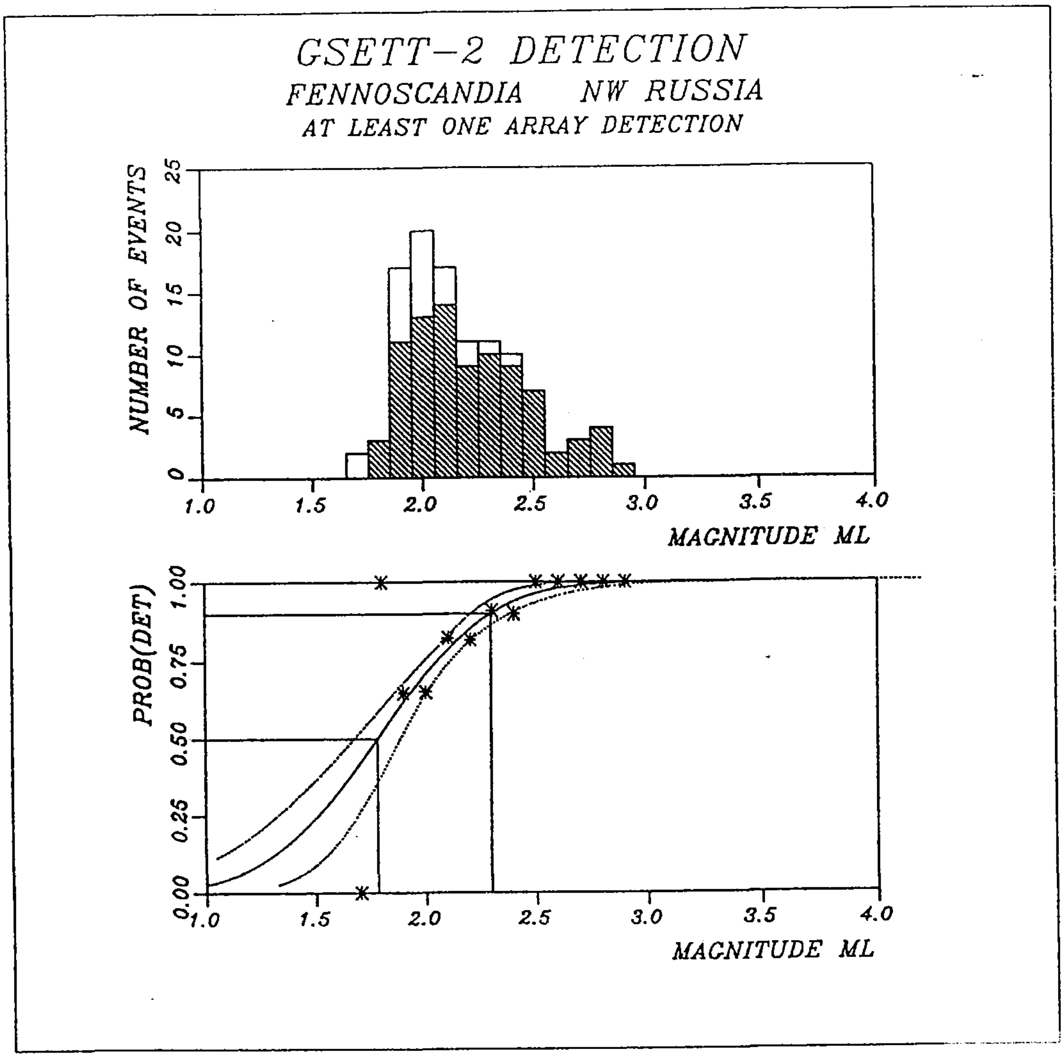

Fig. 7.2.1. Maximum likelihood detectability estimation for Fennoscandia-NW Russia using the Univ. of Helsinki bulletin as a reference. The upper half shows the reference event sct and the number of events actually detected for each magnitude. The lower half shows the maximum likelihood detectability curve and its confidence limits. The actual percentage of detected events at each magnitude is also shown. This figure is based upon a one-array detection requirement.

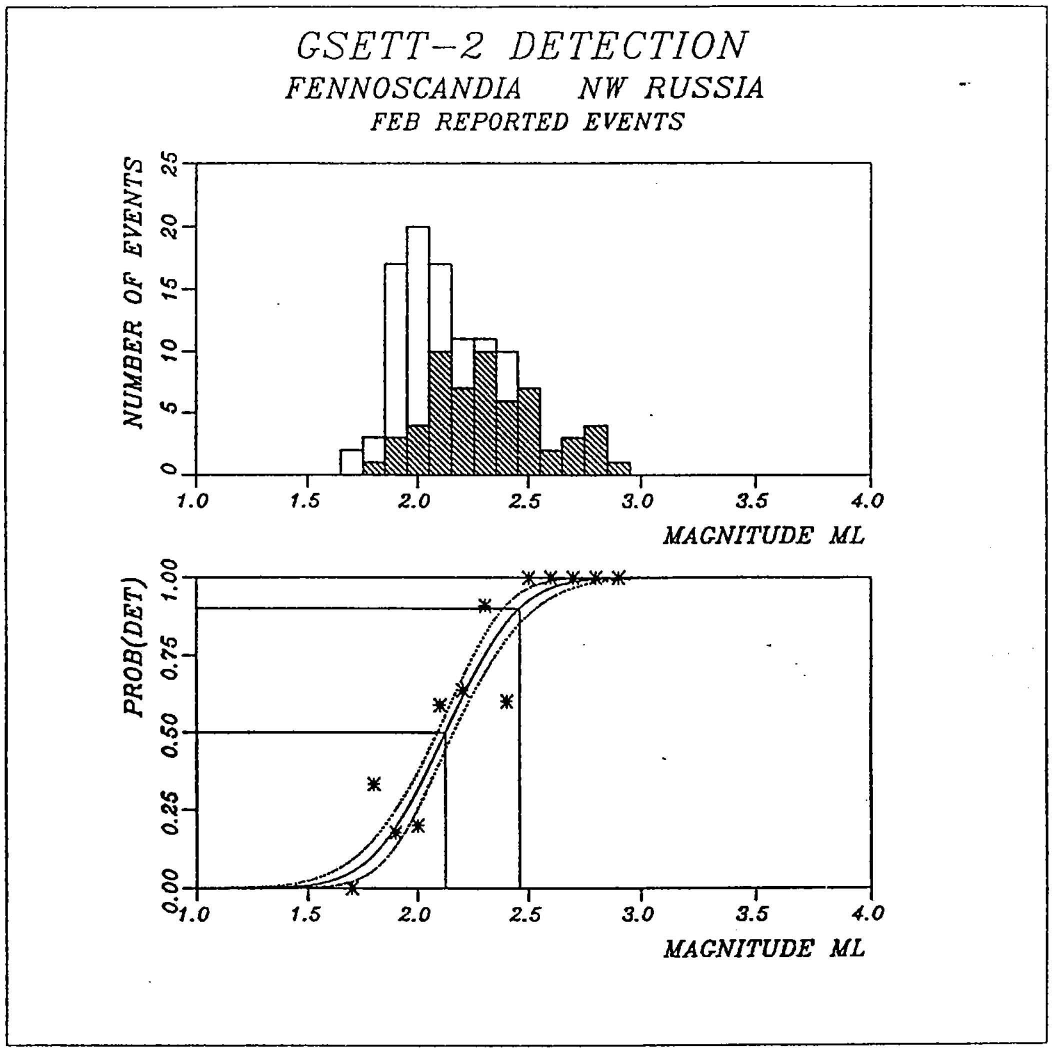

Fig. 7.2.2. Maximum likelihood detectability estimation for Fennoscandia-NW Russia using the Univ. of Helsinki bulletin as a reference. The upper half shows the reference event set and the number of events actually detected for each magnitude. The lower half shows the maximum likelihood detectability curve and its confidence limits. The actual percentage of detected events at each magnitude is also shown. This figure is based upon FEB reported events as discussed in the text.

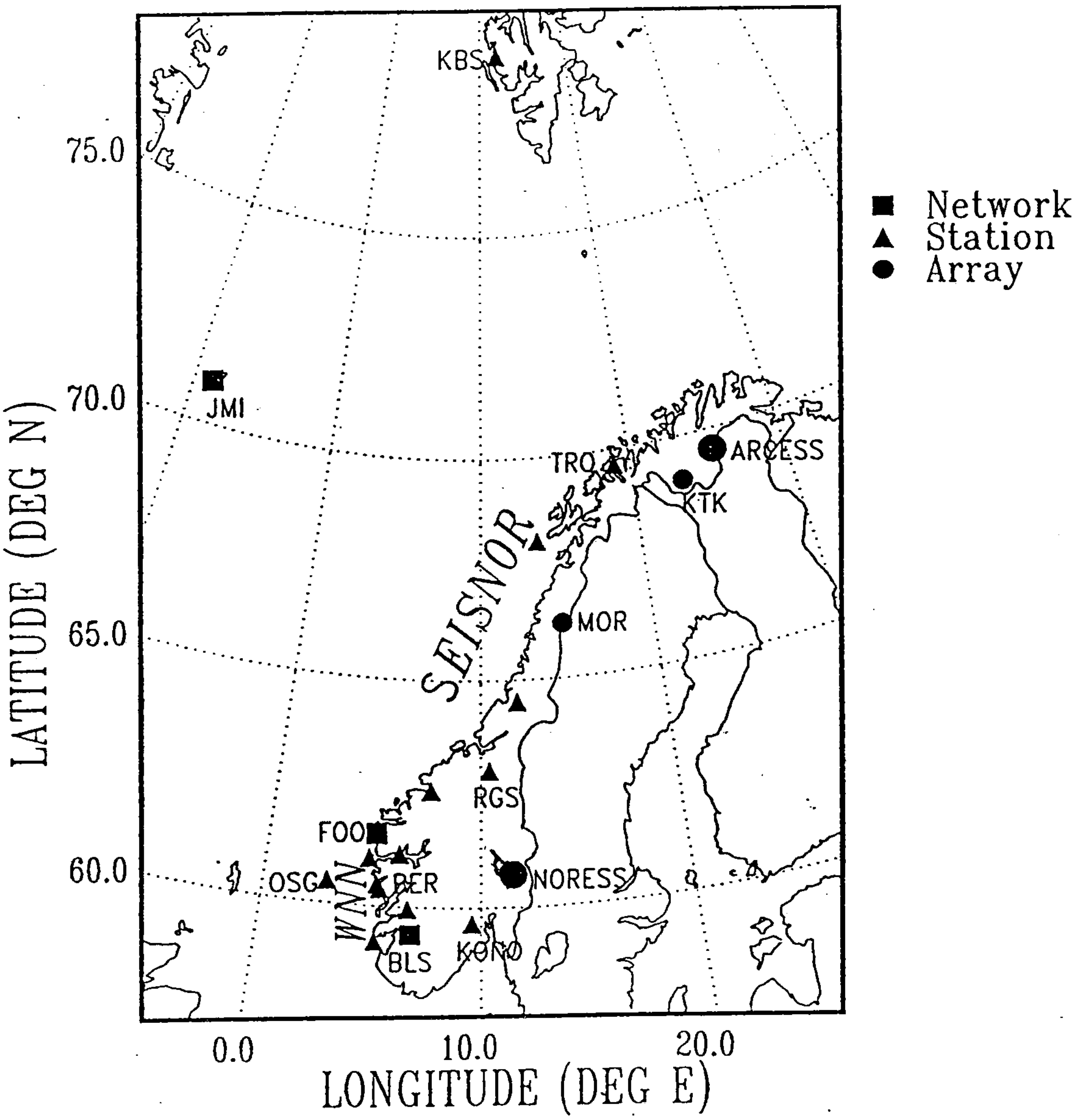

Fig. 7.2.3. The map shows the stations of the WWN and SEISNOR networks operated by the University of Bergen and used in their bulletin work. Note that BLS, FOO and JMI are small networks comprising 4, 3 and 2 stations, respectively, and that MOR and KTK are small-aperture (0.5 km) 6-element arrays. The locations of NORESS and ARCESS are also shown.

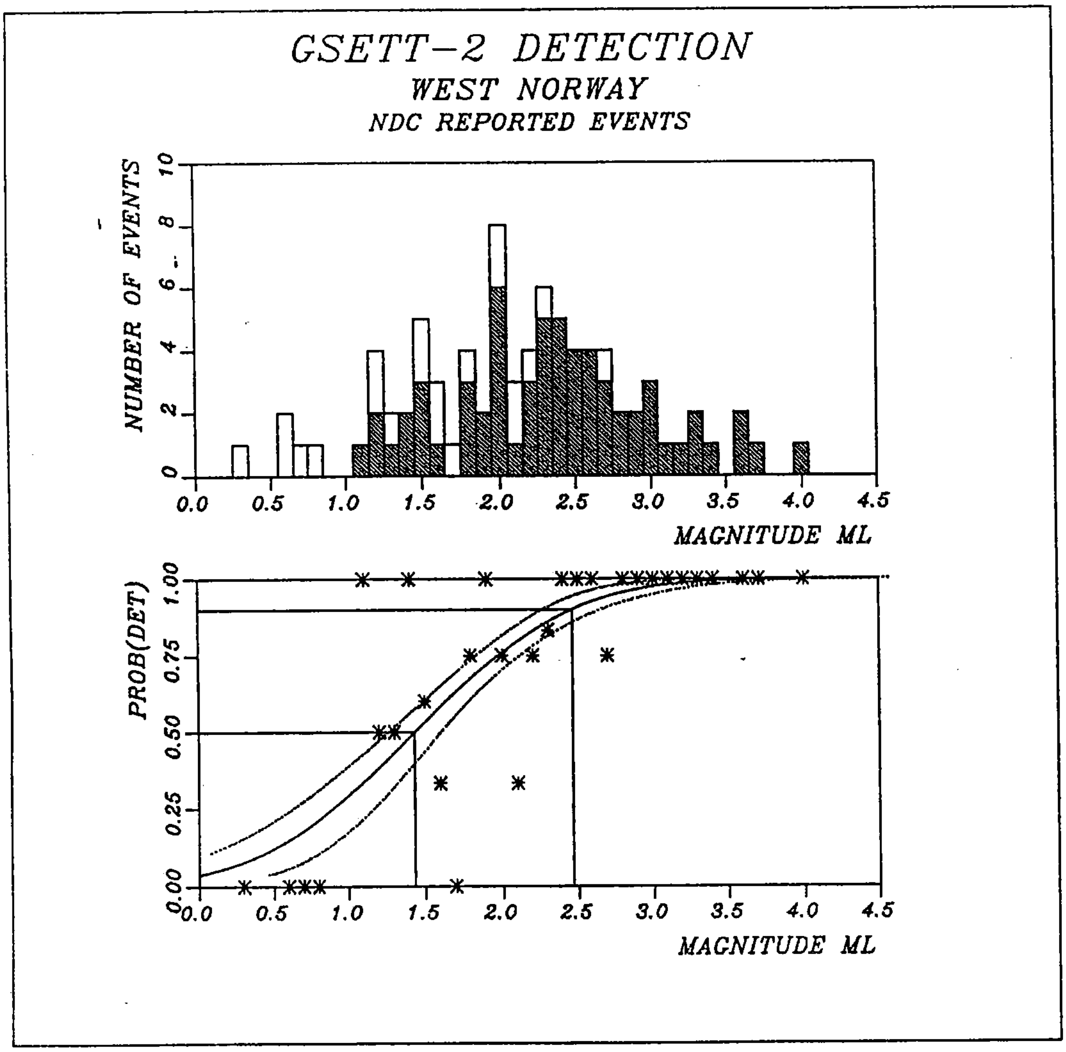

Fig. 7.2.4. Maximum likelihood detectability estimation for western Norway using the Univ. of Bergen bulletin as a reference. The upper half shows the reference event set and the number of events actually detected for each magnitude. The lower half shows the maximum likelihood detectability curve and its confidence limits. The actual percentage of detected events at each magnitude is also shown. This figure is based upon a one-array detection requirement.

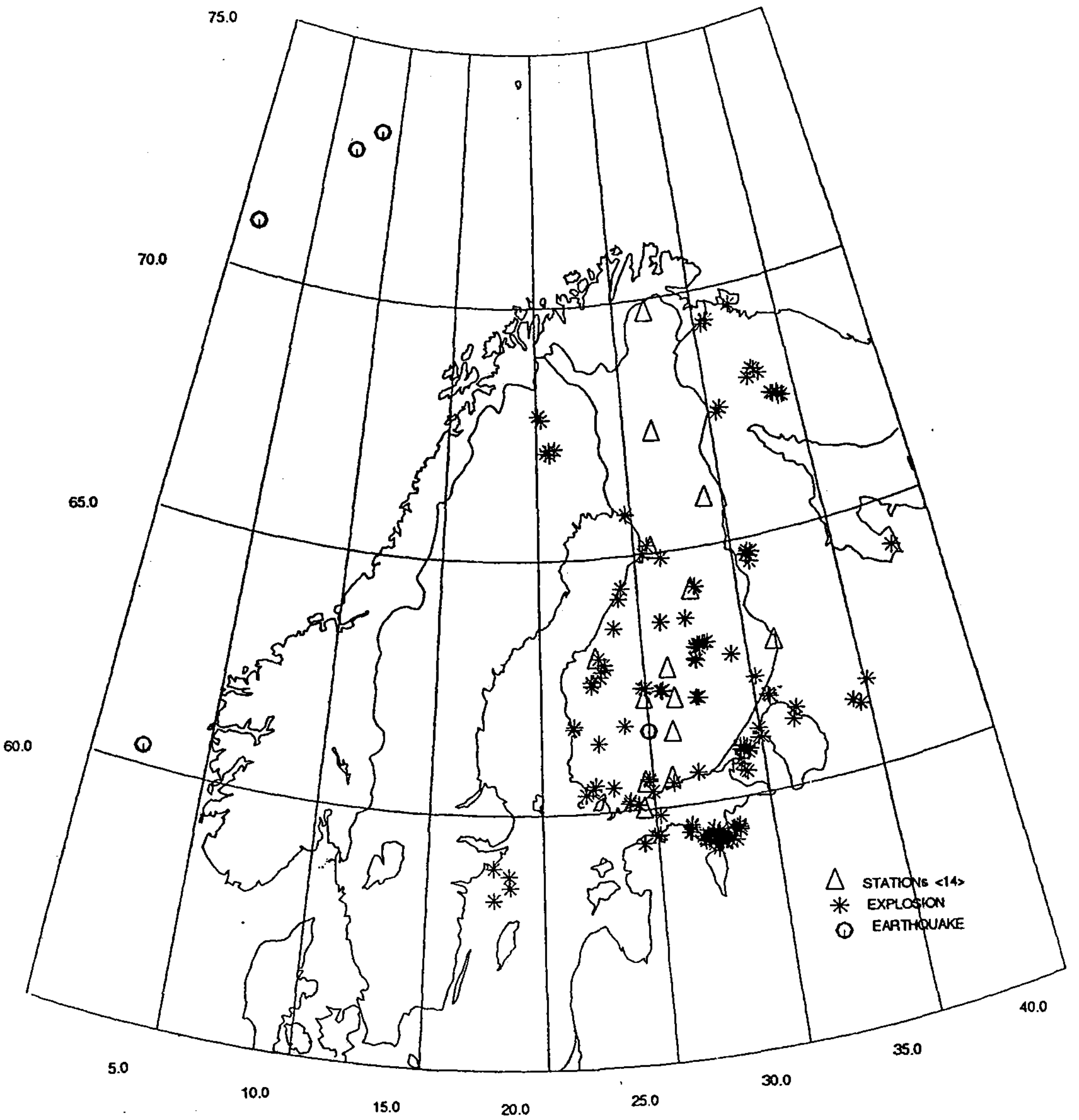

Fig. 7.2.5. Epicenters of the 257 reference events common to the Helsinki bulletin and the FEBs, and stations of the Finnish Seismograph Network. One earthquake (79.89°N, 24.23°E) lies outside the range of the map.

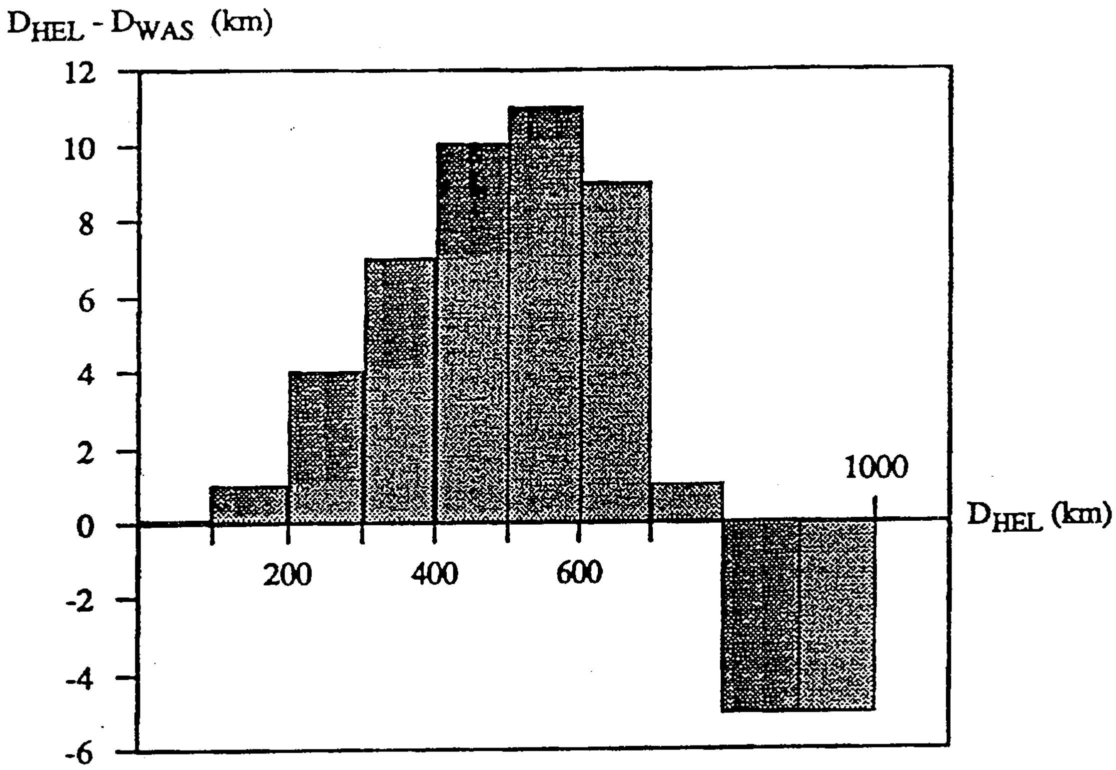

Fig. 7.2.6. The difference between the epicentral distances D_{HEL} and D_{WAS} plotted versus D_{HEL}. D_{HEL} is a distance calculated from the Helsinki velocity model using the travel-time difference of the first arriving P- and S-pair. D_{WAS} is the corresponding distance obtained from the WAS EIDC velocity model.