*Royal Norwegian Council
for Scientific and Industrial Research
(NTNF)*

NORSAR

NORSAR Scientific Report No. 2-89/90

Semiannual Technical Summary

1October 1989 — 31 March 1990

Kjeller, June 1990

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

7.5 Earthquake reporting capabilities in Fennoscandia as inferred from IAS data

For regional seismic arrays and networks in populated areas, operating at frequencies above 1 Hz, it is commonly observed that detections become increasingly dominated by man-made events as the signal-to-noise ratio (SNR) is decreased. It is also known that the spatio-temporal characteristics of natural earthquakes are often quite different from man-made events. Most of the events of antropogenic origin are chemical explosions of some sort.

The Intelligent Array System (IAS) installed at NORSAR is in its present version a system for routine processing and analysis of data from the regional arrays NORESS and ARCESS in Norway (Bache *et al*, 1990; Bratt *et al*, 1990). From September 29, 1989, and to the end of the year the system was operated at the Center for Seismic Studies (CSS) in Arlington, Virginia, USA, and from the beginning of 1990 at NORSAR.

The purpose of the present study is to evaluate the data from the first six months of operation of the IAS, from the point of view of earthquake identification. In doing this, we use available information about the seismicity of the region (Bungum *et al*, 1990), but with no prior assumptions otherwise about where to expect the man-made events.

Data and data analysis

The IAS system is fully automatic, but also supplemented by a thorough analyst review and evaluation. During the 6 months analyzed here, a total of 3813 located events were accepted by the analysts, who refined in one way or another the solutions for all but 669 of these. To further improve the quality of the event locations selected for the present analysis, we have accepted only solutions where the standard error of one observation (sdobs) is less than 3 seconds and where the standard error in time (stt) is less than 10 seconds (Bratt and Bache, 1988). This reduced the number of events to 2454, of which all but 9 are located within the greater Fennoscandian region of 54–76°N, 0–40°E.

The spatial distribution of these events is shown in Figs. 7.5.1a-c, revealing a pattern quite different from the known seismicity in the area, and with a non-uniform time-of-day (TOD) distribution as shown in Fig. 7.5.1d. This distribution contrasts strongly to that expected for earthquakes, with no dependence on time-of-day. There are two prominent peaks in the distribution, right ahter noon and around midnight. In fact, the amount of man-made events (explosions) in the data base is larger than what is indicated by Fig. 7.5.1d, since different areas should be expected to have their explosions peaks at different times of the day, thereby cancelling each other to some extent.

Our aim in the present study has been to identify areas with a significant number of explosions, and to flag these events in the data base. Our approach in this respect has been first to identify epicentral areas where the events are concentrated or clustered. A non-uniform TOD distribution and/or a non-exponential magnitude-frequency (MF) distribution then indicates the presence of man-made events within that area. The best way to do this analysis is to start with large areas or regions, and then to zoom in on smaller areas later.

For areas thus identified to contain a certain amount of explosions, we define one or more hourly intervals within which all events below a certain magnitude should be flagged as explosions in the data base. These hourly intervals coincide with peaks in the TOD distributions, while the magnitude thresholds depend on the character of the MF distributions within as well as outside of these intervals. The parameters should be tuned in such a way as to yield (after flagging of explosions) both TOD and MF distributions for the remaining events that are compatible with what should be expected for earthquakes.

After screening or filtering the entire data base in this way, we evaluate what this filtering represents in terms of magnitude thresholds for accepting events (as natural earthquakes) from particular areas, at different times of the day. These thresholds reflect in the present context the capabilities for reporting natural earthquakes, limited by a noise level which in this case is determined by the occurrence of man-made events.

The actual analysis for the IAS data base involved the testing of a large number of spatial windows, in order to identify areas with non-uniform TOD distributions and non-exponential MF distributions. The result of this analysis for the present data base of 2454 Fennoscandian event locations are the 52 TOD filters defined in Table 7.5.1. The spatial windows are shown also in Figs. 7.5.1a-c, and the TOD distributions for a selection of these windows are shown in Table 7.5.2.

In some cases, a spatial window is defined entirely within the area covered by another window. In that case, the smaller window has a higher magnitude threshold. In other cases, one window has two different hourly intervals connected to it, which is done by defining two different windows. After the first 47 windows were defined (only those are shown in Figs. 7.5.1a-c), it was found necessary to define also four larger regional windows (No 48–51), but with magnitude limits below the smaller windows covered inside. In addition, the last window (No 52) covers the entire area under analysis, for the purpose of defining a lower magnitude limit for all the events (here set to 0.5). From Table 7.5.1 it is seen that the other windows have magnitude limits ranging from 1.5 to 3.3.

After TOD filtering, there are 75 events remaining of the original 2454, or about 3%. These events are plotted in Fig. 7.5.2, with TOD distributions as shown in Fig. 7.5.1d and in in the last column of Table 7.5.2. It is likely, when studying the TOD distribution and also when comparing with earlier seismicity maps, that some explosions still remain in the data base. This is because they occur in areas with few other events, because they occur at TODs shared by few other events from the same area, or because they have magnitudes above other events from the same area and with the same TODs.

While it is likely that the TOD filtering has not removed all of the explosions, it is even more certain that some natural earthquakes have been removed. The latter is evident from the fact that what we have done is simply to remove all of the events below a certain threshold magnitude, a threshold which has been made dependent on region and TOD. In the cases when natural earthquakes occur within these spatio-temporal-magnitude windows, they will of course be flagged as explosions.

Earthquake reporting capabilities

The results of the above analysis for six months of available IAS data determines a threshold for the reporting of natural earthquakes, provided that no discrimination analysis of individual events has been performed. The key to this threshold, and the way in which it varies in time and space, is found in the definition of the TOD filters (Table 7.5.1).

We have developed a procedure for time dependent spatial contouring of this threshold by defining first an hourly time interval and a regular spatial grid. For each grid point, we loop through all TOD filters in order to identify those that contain the point, and a hit is declaired if there is some overlap between the selected hourly interval and the filter's hourly interval. The magnitude threshold for the selected grid point is then taken from the filter with the highest threshold. This procedure is repeated for all points in the grid, all of which are associated with a threshold magnitude applicable within the selected TOD interval. A threshold contouring can then be performed on this basis.

In the present case, we have defined a grid with steps 0.5° in latitude and 1° in longitude. The resulting contours (with some spatial smoothing) is shown in Fig. 7.5.2a-b for a time period (1030–1430 UTC) during the peak of the working hours, and in Fig. 7.5.2c-d for a time period (0030–1430 UTC) during the most quiet part of the night. The difference between the two is very significant: while the noise level (reporting threshold) at night time extends up to 1.5 in magnitude only in very few areas, the level in the middle of the day extends up to 2.5 over fairly large areas.

Discussion and conclusions

The hourly time period used in the examples above is somewhat arbitrarily set to 4 hours. The length of the time interval should reflect the particular purpose of the analysis, but it should also reflect the time resolution assumed in the definition of the TOD filters. A similar resolution consideration applies also to the determination of the grid size, which should reflect the purpose of the analysis as well as the resolution assumed in the definition of the TOD filters.

One of the limitations with the present data base is that it is based on observed data from only two regional arrays. However, even if this leads to a certain variation in both detection thresholds and location precisions over the area covered in this study, it should not affect the results significantly. The reason for this is partly that the poorest locations have been removed prior to the analysis, but first of all that a substantial amount of the explosions are in fact located more or less randomly outside of the main known explosion sites. Better locations should therefore only be expected to lead to minor changes in the space-time organization of the data.

The spatial windows as defined in this study are very simple, reflecting to some extent the limitations in location precisions. A natural refinement here would be to define windows in terms of polygones, an option which in fact is available in the sorting program used in this study. In the present first order approach, however, simple rectangular spatial windows are considered satisfactory.

Another natural refinement of the window definitions would be to include weekly and seasonal variations, both of which are known to be considerable. The weekly variation shows for most of the areas a stable weekend minimum (Bratt *et al*, 1990), while the seasonal variations probably are more complicated. An inclusion in the filter definitions of such variations is quite straightforward, however.

The explosion filters and associated noise levels defined in this work are of course applicable in general only for the time period for which they has been derived. However, only minor adjustments should normally be expected to be necessary in order to apply the present results to other time periods. It would be desirable to combine such an extention with the refinements discussed above. Similarly, the approach taken here should also be easy to apply to any new area from which event location data of similar nature are available.

What has been shown here is that the detectability now possible through a network of regional arrays cannot be fully utilized unless a substantial effort is being directed into the problem of event identification and discrimination. Being interested in earthquakes or explosions are two sides of the same question in this respect, pursuable through the same approaches, methods and algorithms.

To be most useful, the discrimination algorithms, whether they are based on focal depth, spectral features, spectral ratios, etc. (e.g. Hedlin *et al*, 1990), should to the largest possible extent be included in the routine analysis of the events, with options for refinements and improvements as part of the analyst reviews as well as in subsequent offline analyses. These results should follow the events into the data base and be expressed in ways that could facilitate the computation of probabilities for the events being natural earthquakes or not.

In conclusion, we have found through a regionalized time-of-day analysis of six months of IAS data from the regional arrays NORESS and ARCESS shows that about 97% of the more well-located events probably are of man-made origin. Based on the derived information about where and when the man-made events occur, contour maps (in magnitude) of associated capabilities for reporting natural earthquakes are provided, for different times or hourly intervals of the day. The magnitude limits vary from about 3.0 as a maximum in some mining areas and down to less than 1.0 for western and northern Norway offshore areas, where most of the man-made disturbances are still below the detection level.

These results call for a dedicated effort into event discrimination work, with algorithms to be included preferably already in the routine analysis of the data.

Acknowledgements

This work was done while the author was a visiting scientist at Science Applications International Corporation (SAIC) in San Diego, CA.

H. Bungum

References

Bache, T.C., S.R. Bratt, J. Wang, R.M. Fung, C. Kobryn and J. Given (1990): The Intelligent Monitoring System, Accepted for publication in *Bull. Seism. Soc. Am.*.

Bratt, S.R. and T.C. Bache (1988): Locating events with a sparse network of regional arrays, *Bull. Seism. Soc. Am.*, 78, 780–798.

Bratt, S.R., H.J. Swanger, R.J. Stead, F. Ryall and T.C. Bache (1990): Initial results from the Intelligent Monitoring System, Accepted for publication in *Bull. Seism. Soc. Am.*.

Bungum, H., A. Alsaker, L.B. Kvamme and R.A. Hansen (1990): Seismicity and seismotectonics of Norway and nearby Continental Shelf areas, Submitted for publication.

Hedlin, M.A.H., J.B. Minster and J.A. Orcutt (1990): An automatic means to discriminate between earthquakes and quarry blasts. Accepted for publication in *Bull. Seism. Soc. Am.*.

No	La1	La2	Lo1	Lo2	M_L	H1	H2	No	La1	La2	Lo1	Lo2	M_L	H1	H2
1	59.6	61.0	4.8	6.0	1.6	9	17	27	59.0	60.0	26.0	30.3	3.0	8	15
2	61.6	62.8	5.2	8.0	1.6	9	17	28	62.9	63.4	27.0	29.2	2.5	11	12
3	58.0	59.1	5.3	7.8	1.6	13	17	29	60.0	61.5	27.5	30.3	2.6	9	15
4	59.1	60.3	6.0	7.3	1.6	10	17	30	60.6	61.4	28.5	29.8	3.0	12	13
5	60.3	61.2	6.0	7.5	1.6	9	17	31	60.8	62.2	30.3	32.0	2.7	9	15
6	56.5	58.0	7.0	11.0	1.6	10	12	32	59.3	60.1	33.0	35.0	2.9	8	12
7	62.0	62.7	8.6	10.0	1.6	10	19	33	61.2	63.2	34.0	37.0	2.8	9	14
8	58.7	60.2	9.0	12.0	1.6	7	16	34	65.3	68.5	15.0	19.5	1.8	0	24
9	57.5	58.7	11.5	14.4	1.6	9	15	35	68.5	70.0	18.2	22.4	1.5	8	19
10	58.7	60.0	12.0	14.2	1.6	10	17	36	66.5	68.2	19.5	22.8	1.6	0	15
11	54.0	56.0	12.5	17.5	2.5	6	16	37	66.5	68.2	19.5	22.8	2.4	16	24
12	54.6	55.9	15.8	17.0	2.9	0	24	38	70.0	71.5	23.0	31.0	1.6	9	14
13	59.1	60.4	14.2	16.0	1.6	0	24	39	67.2	68.0	23.2	25.4	1.9	6	24
14	60.4	61.3	14.5	16.3	1.6	9	13	40	64.7	66.6	23.9	27.6	2.1	7	20
15	58.3	59.2	18.0	19.1	3.0	6	19	41	66.8	68.3	29.5	35.2	2.0	0	24
16	57.5	59.8	17.2	19.5	2.4	9	14	42	66.8	68.3	29.5	35.2	2.6	3	20
17	54.0	55.4	18.3	21.0	2.5	9	18	43	67.1	67.9	32.6	35.2	3.3	5	19
18	59.3	60.2	20.0	22.3	2.7	7	13	44	68.3	69.8	29.7	33.4	2.0	0	24
19	60.8	61.7	20.0	21.5	2.0	8	14	45	68.9	69.8	29.7	32.0	3.1	11	12
20	54.0	57.5	22.0	32.0	2.5	9	14	46	64.5	65.1	29.9	31.8	2.8	9	12
21	62.0	63.8	22.0	27.0	2.0	9	12	47	68.8	69.8	33.4	36.0	2.4	7	11
22	63.8	64.4	23.1	25.8	2.3	9	13	48	53.0	61.0	9.0	21.0	1.5	6	15
23	59.0	60.0	23.7	26.0	2.5	9	16	49	56.0	62.0	21.0	32.0	2.1	7	15
24	60.0	62.0	25.0	27.5	2.6	0	1	50	62.0	68.0	15.0	25.0	1.8	6	14
25	60.0	62.0	25.0	27.5	2.6	11	15	51	62.0	69.0	25.0	40.0	2.1	8	15
26	57.6	59.0	25.6	27.0	2.6	9	13	52	50.0	80.0	-10.	50.0	0.5	0	24

Table 7.5.1. Time-of-day (TOD) filters as developed in this study for the purpose of removing presumed explosions from the IAS data base of event locations in Fennoscandia. The columns are filter (spatio-temporal window) number, latitude and longitude limits, magnitude limit and time-of-day limits. The last of the filters (52) covers the entire region under analysis, thereby defining a lower magnitude threshold for accepting any event.

Window Hour	7	8	9	13	27	28	29	36	39	40	41	44	46	All	Final
0- 1	0	0	0	6	0	0	0	5	0	1	9	5	0	35	5
1- 2	0	1	0	5	0	0	0	7	0	0	12	4	0	39	3
2- 3	0	0	0	0	1	0	0	3	0	0	10	6	0	26	3
3- 4	0	0	0	0	0	0	0	4	0	0	13	15	0	40	2
4- 5	0	0	0	0	0	0	0	1	0	0	14	11	0	32	0
5- 6	0	0	0	1	0	0	0	9	0	0	13	1	0	29	2
6- 7	0	0	0	2	0	0	0	3	2	0	8	0	0	27	2
7- 8	0	2	1	8	0	0	0	9	2	2	11	11	0	53	1
8- 9	1	5	0	3	1	0	0	11	1	0	15	11	0	59	0
9-10	1	6	2	1	3	0	1	10	1	0	27	15	3	125	4
10-11	4	4	2	1	12	0	1	9	4	3	25	16	13	130	2
11-12	0	7	4	6	18	3	2	6	1	17	69	21	4	202	1
12-13	0	13	5	2	34	12	19	5	17	9	79	73	5	253	5
13-14	1	17	9	4	15	0	12	17	9	2	36	45	0	245	7
14-15	4	22	12	3	9	0	6	23	8	2	19	13	0	186	4
15-16	5	7	10	21	2	1	2	10	4	4	11	2	0	128	4
16-17	2	3	0	2	0	0	0	14	2	5	9	3	0	57	6
17-18	0	1	0	3	0	0	0	20	2	1	12	2	0	62	2
18-19	0	0	0	6	0	0	0	33	1	10	8	4	0	70	4
19-20	18	0	0	0	1	0	0	15	1	3	13	2	0	65	5
20-21	0	0	0	1	0	0	0	12	0	2	14	4	0	44	5
21-22	2	0	0	1	0	0	0	24	1	0	8	1	0	46	3
22-23	1	0	1	0	0	0	0	124	0	0	6	3	0	139	3
23-24	0	0	0	3	0	0	0	227	1	0	12	3	0	253	2

Table 7.5.2. Time-of-day (TOD) distributions for the spatio-temporal windows (filters) defined in Table 7.5.1 that have more than 10 events in any particular hourly interval. The two last columns (shown also if Fig. 7.5.1d) give the distribution in the original data base and in the filtered one, respectively.

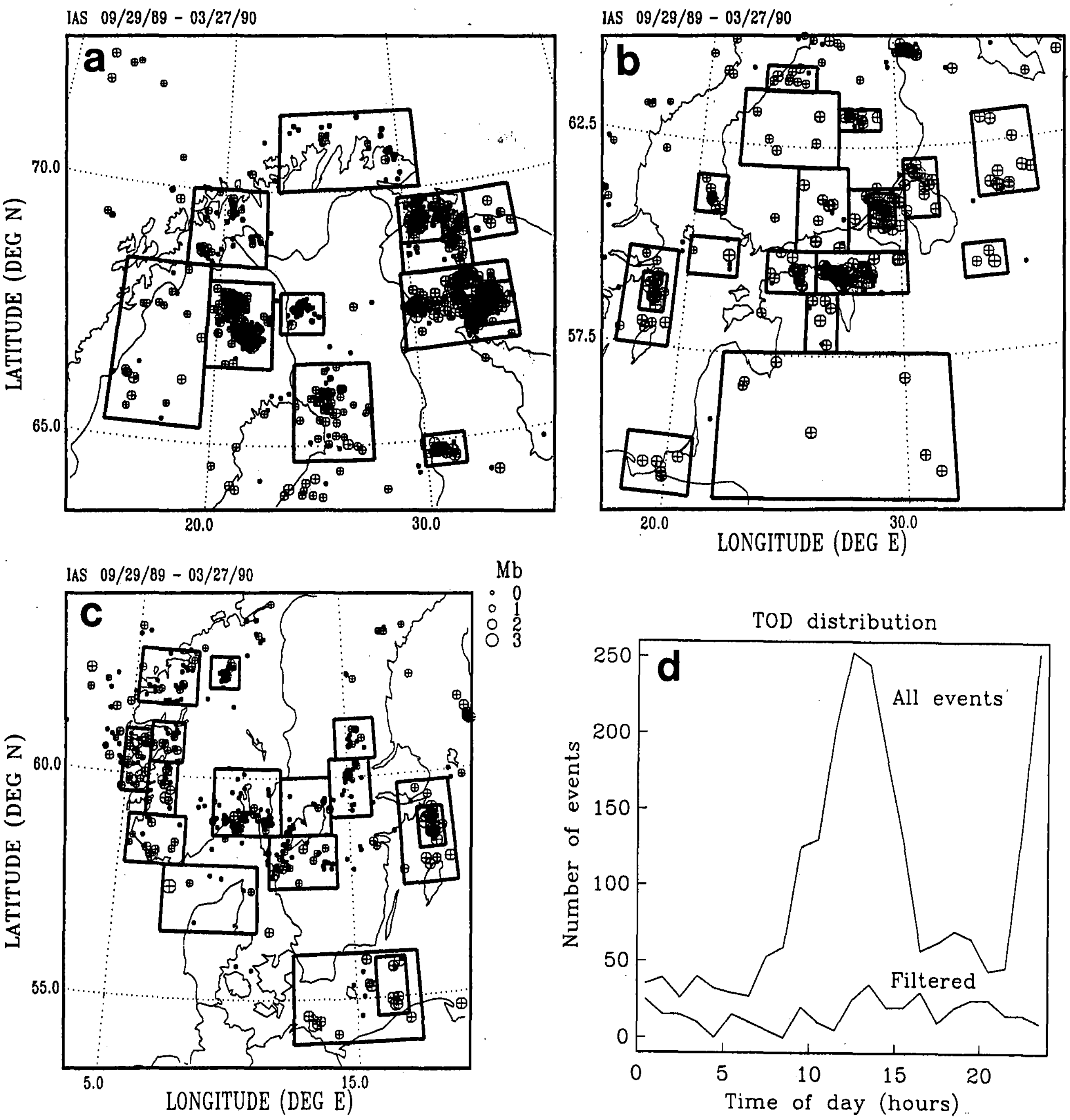

Fig. 7.5.1. Unfiltered IAS event locations for (a) northern, (b) eastern and (c) western Fennoscandia. The boxes are the spatial windows defined in Table 7.5.1, used in removing man-made events. In (d) is shown the time-of-day (TOD) distribution for the unfiltered data ('All events') together with the TOD distribution for the events remaining after application of the TOD filters ('Filtered'). The latter distribution has been scaled up by a factor of 5. The actual numbers for these two distributions are given in the last two columns of Table 7.5.2.

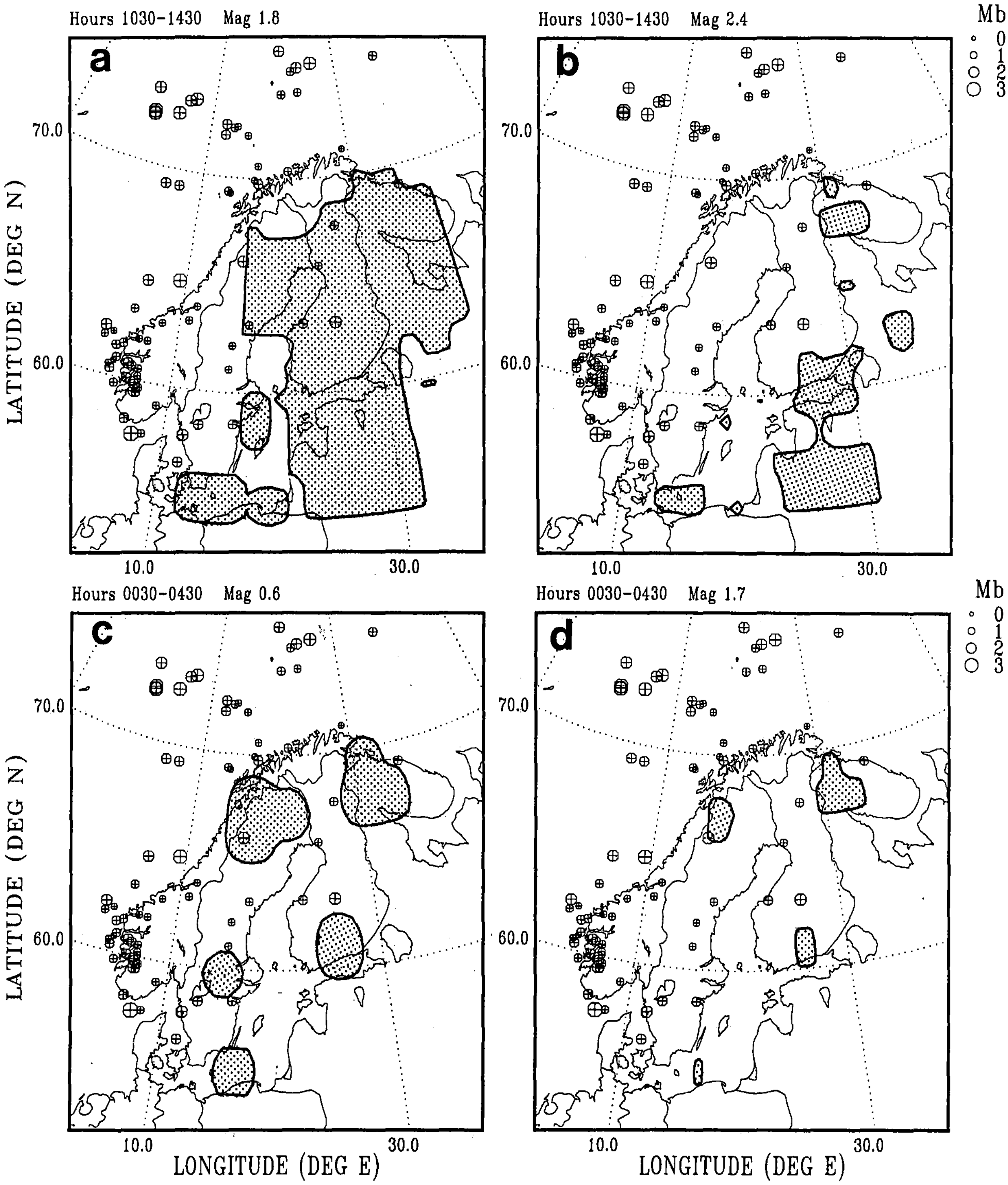

Fig. 7.5.2. Contour maps for the magnitude thresholds defined by the TOD filters developed in this study. The four maps correspond to (a) magnitude level of 1.8 for the hours between 1030 and 1430 UTC, (b) magnitude 2.4 for 1030–1430, (c) magnitude 0.6 for 0030–0430 and (d) magnitude 1.7 for 0030–0430. Under certain conditions, these contours indicate the day-time reporting capabilities for natural earthquakes.