Royal Norwegian Council
for Scientific and Industrial Research
(NTNF)

NORSAR

NORSAR Scientific Report No. 2-92/93

Semiannual Technical Summary

1 October 1992 — 31 March 1993

Kjeller, July 1993

7 Summary of Technical Reports / Papers Published

7.1 Intelligent post-processing of seismic events -- Part 1: Basic approach

Introduction

This is the first in a series of three contributions in this report addressing the topic of intelligent post-processing of seismic events. In this first contribution we discuss how to subdivide the area to be monitored in order to identify sites of particularly high seismic activity. We further introduce the basic idea behind this post-processing technique, which is to use as a starting point the initial event location provided by the Intelligent Monitoring System (IMS) and then use region-specific information to refine the solution. By applying this technique to areas with significant recurring seismic activity, such as mining sites, a considerable part of the analyst work can be eliminated.

Since 15 October 1991, the Intelligent Monitoring System (IMS, Bache et al, 1993) has been processing seismic data from four high-frequency arrays in northern Europe. These are NORESS and ARCESS in Norway, FINESA in Finland and GERESS in Germany. During October 1992 a small-aperture array was installed near Apatity on the Kola peninsula, and during late October/early November 1992 another small-aperture array on the island of Spitsbergen became operational. The data from these installations are now included in the IMS processing for the production of the event bulletin.

Since four of the arrays providing data to the IMS are located in Fennoscandia, see Fig. 7.1.1, the IMS event bulletin shows an excellent event detection capability for this region. Ringdal (1991) found that for Fennoscandia/NW Russia, a network consisting of NORESS, ARCESS and FINESA has a 90% detection capability close to M_L 2.0. Near the individual arrays, the detection capability is considerably better, and consequently a large number of events less than M_L 1.0 are detected.

IMS event statistics

The basic principle of the post-processing method is to start by subdividing the area to be monitored into smaller areas, and subsequently apply region-specific analysis to each such area. As an example, we will consider in some detail the statistics of events in Fennoscandia and NW Russia for the 18-month time period 10/15/91 - 04/15/93. We will only consider "well-defined" events; thus we ignore events with author identification "yes/no" and "ESAL/Poor_Loc" in the origin table.

For the time period 10/15/91 to 04/15/93 the IMS bulletin contains 19503 well-defined events. 65.6% (12799) of these events are located in the Fennoscandian/NW Russian region defined by the map of Fig. 7.1.2, 15.8% (3089) are located within 5 degrees of the GERESS array, and the remaining 18.5% (3615) are distributed around the rest of the world, mostly at teleseismic distances from the regional array network.

Figs. 7.1.2-7.1.4 show the event distribution in Fennoscandia for all magnitudes, $M_L > 1$ and $M_L > 2$, respectively. In each figure, we have marked the approximate geographical extent of 8 main mining areas. Table 7.1.1 lists these mining sites and gives details on the number and percentages of events associated to the sites at various magnitudes.

From the three figures and Table 7.1.1 we can make the following general observations:

- Out of the total 12799 events, 6317 (49.4 per cent) are above $M_L = 1$, and only 1131 (8.8 per cent) are above M_L 2.
- The total percentage of events associated with the 8 mining sites is 47.88% (all magnitudes), 56.66% ($M_L > 1.0$) and 65.61% ($M_L > 2.0$). Thus, these sites become more dominant for the largest events, in terms of relative number of events reported.
- Some mining sites have a relatively high proportion of large events ($M_L > 2.0$). This is particularly noticeable for the mining areas in Western Russia/Estonia. On the other hand, the Kiruna mine has the largest number of events altogether, but almost none of these are above M_L 2.

Being based on about 1 1/2 year of data, the statistics discussed here should be reasonably representative for the situation in the Fennoscandian/NW Russia region. Thus, analysis of recurring events from these mining areas is a significant workload for the analyst. An automatic method to improve the automatic analysis so as to obtain location precisions comparable with the analysts' results would be a significant development. In this and the next two sections of this report, we will show that such an improvement is possible for a well-calibrated mining area (the Khibiny Massif).

General outline of the method

Most automatic detection processor algorithms work without any ***a priori*** assumptions as to when and where a seismic event occurred. This is, of course, quite reasonable, and to some extent inevitable. The detector (SigPro) associated with the IMS works in this way. As a result, some of the SigPro output parameters, which later will be used by the IMS ESAL system, are less than optimum.

However, once an initial event location is given by the IMS, it is possible to use this initial location successively in an automatic iteration scheme. Each iteration gives a more precise location, which in turn allows the automatic program to place successively stronger constraints on the processing parameters.

As a first example (see Section 7.2), we can consider the estimation of signal arrival time. Given that an event has occurred in a certain area, the automatic program can select a set of optimum filter bands and beam parameters for this area, prior to reassessing the arrival time estimate. As shown in Section 7.2, this can lead to a remarkable improvement in timing precision. The examples given in Section 7.2 make use of an autoregressive likelihood technique (Pisarenko et al, 1987; Kushnir et al, 1990). It is noteworthy that this method seems to require that the search be limited to a relatively short time window in order to work well. If an initial location and origin time is known, we can obtain the required short time window for the search. The method is therefore well suited to a post-processing application.

Another example is the estimation of azimuth from either arrays or three-component stations. The advantage of using a fixed frequency interval for broadband F-k analysis was convincingly demonstrated by Kværna and Ringdal (1986). Again, a prerequisite was the knowledge that the event in question was located in a certain known area.

Section 7.3 demonstrates that the approach of doing post-processing based on IMS initial solutions has the potential of providing an order-of-magnitude improvement in location precision, at least in certain cases such as the Khibiny Massif near the Apatity array. The improvement may be less if no network station is located close to the source, but it should still be significant. For example, the data from Kværna and Ringdal (1986) indicate that a single array (NORESS) would be capable of locating the Blåsjø explosions to within an accuracy of 10 km or better at a distance of 300 km. This is compared to the typical uncertainty of about 30 km in traditional single-array location estimates at this distance (Mykkeltveit and Ringdal, 1981).

In general, it is true that regional corrections are required in order to compute an optimum location. Again, the post-processing analysis is well suited toward this end, because the corrections can be tied to the general area, to which the initial IMS processing assigns the event.

In this context, it is important to note that no regional travel-time tables need to be involved as long as an adequate set of calibration events for the general area are available. The corrections for systematic bias may be made both to the phase arrival times and to the estimated azimuths. Again, this subject will be discussed in detail in Section 7.3, in connection with an applicaiton of the method to the Khibiny Massif area in the Kola peninsula.

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Region	All Mag		Mag > 1.0		Mag > 2.0	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Fennoscandia/NW Russia	12799	100.00	6317	49.36	1131	8.84
Estonia	1487	11.62	1159	18.36	225	19.89
Karelia	379	2.96	212	3.36	70	6.19
Khibiny	1374	10.74	1106	17.51	233	20.60
Kiruna	1953	15.26	634	10.04	11	0.97
Kostomuksha	69	0.54	69	1.09	47	4.16
Kovdor	112	0.88	99	1.57	34	3.01
Nikel	620	4.84	181	2.87	104	9.20
Siilinjaervi	134	1.05	119	1.88	18	1.59
Total for 8 mines	6128	47.88	3579	56.66	742	65.61

Table 7.1.1. Distribution of events in mining regions of Fennoscandia and NW Russia. Events with author identificantion "yes/no" and "ESAL/Poor_Loc" in the origin table are not included in the statistics.

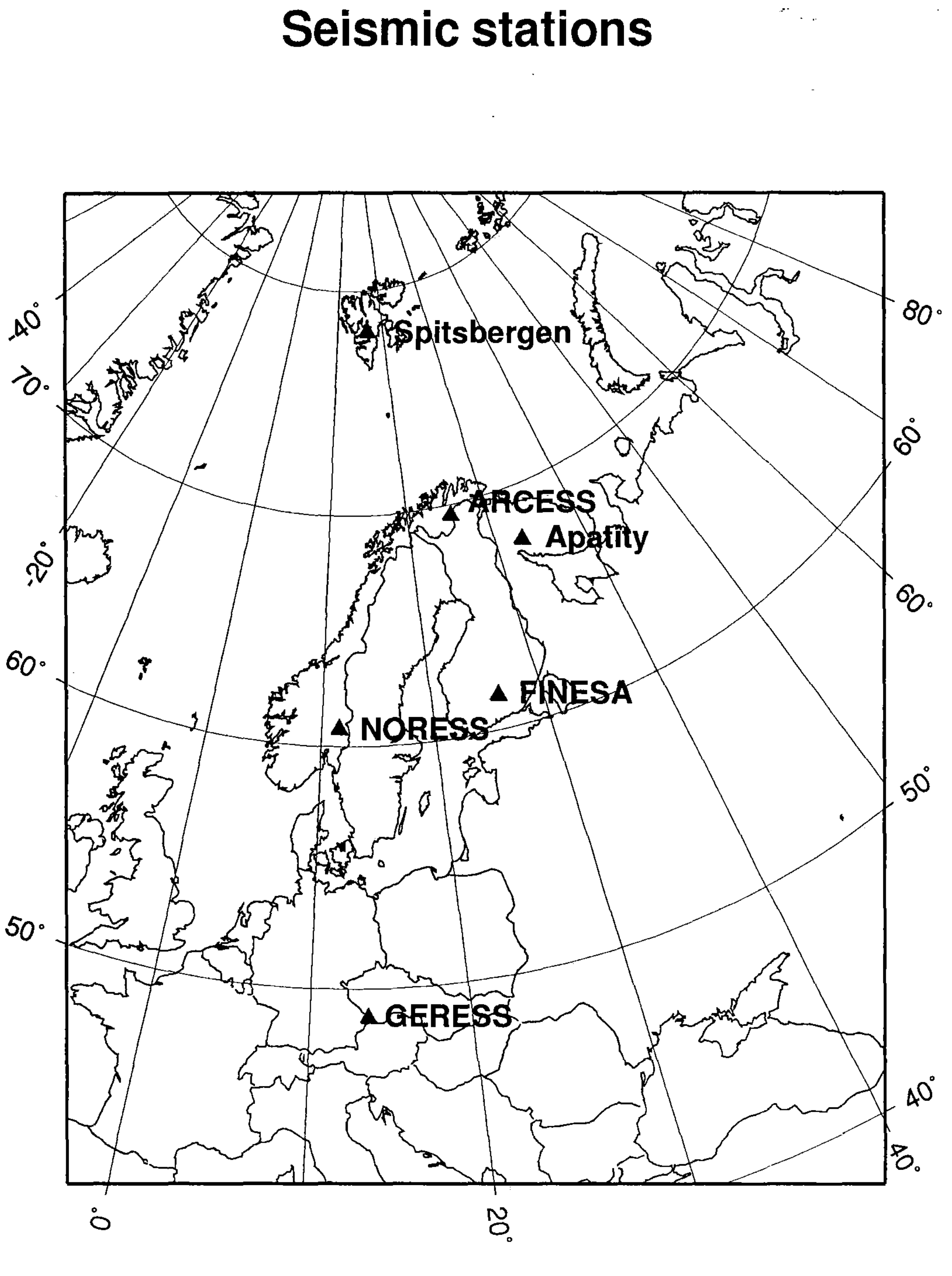

Fig. 7.1.1. Map showing the location of the regional arrays currently used by the Intelligent Monitoring System in operation at the NORSAR processing center.

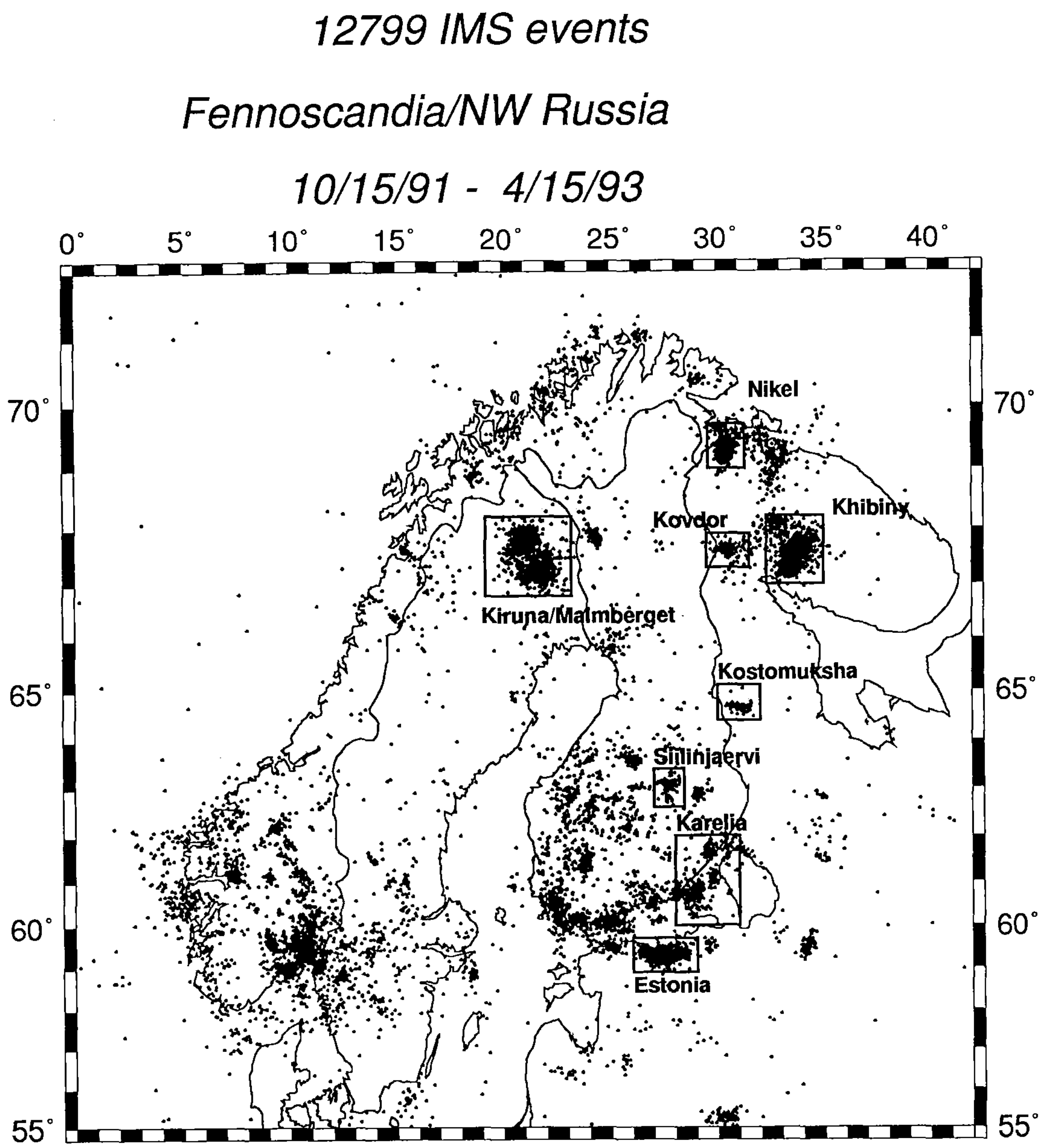

Fig. 7.1.2. Location of 12,799 events (all magnitudes) processed by the IMS for an 18-month period. Only event solutions of satisfactory quality have been included (see text for details). Note the concentration of events in selected mining areas.

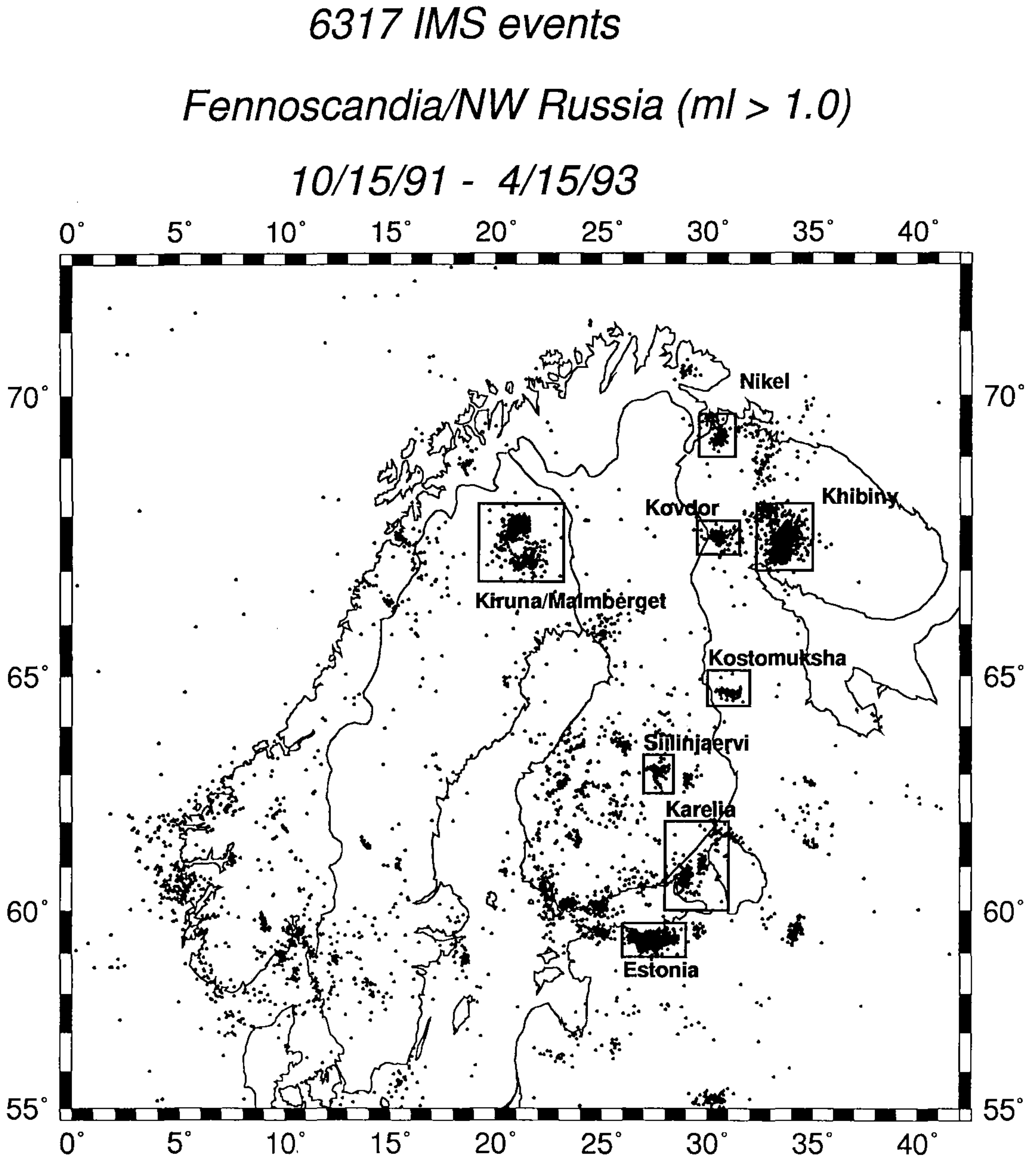

Fig. 7.1.3. Same as Fig. 7.1.2, but showing only events of $M_L > 1.0$. The total number of events is 6317 for the 18-month period.

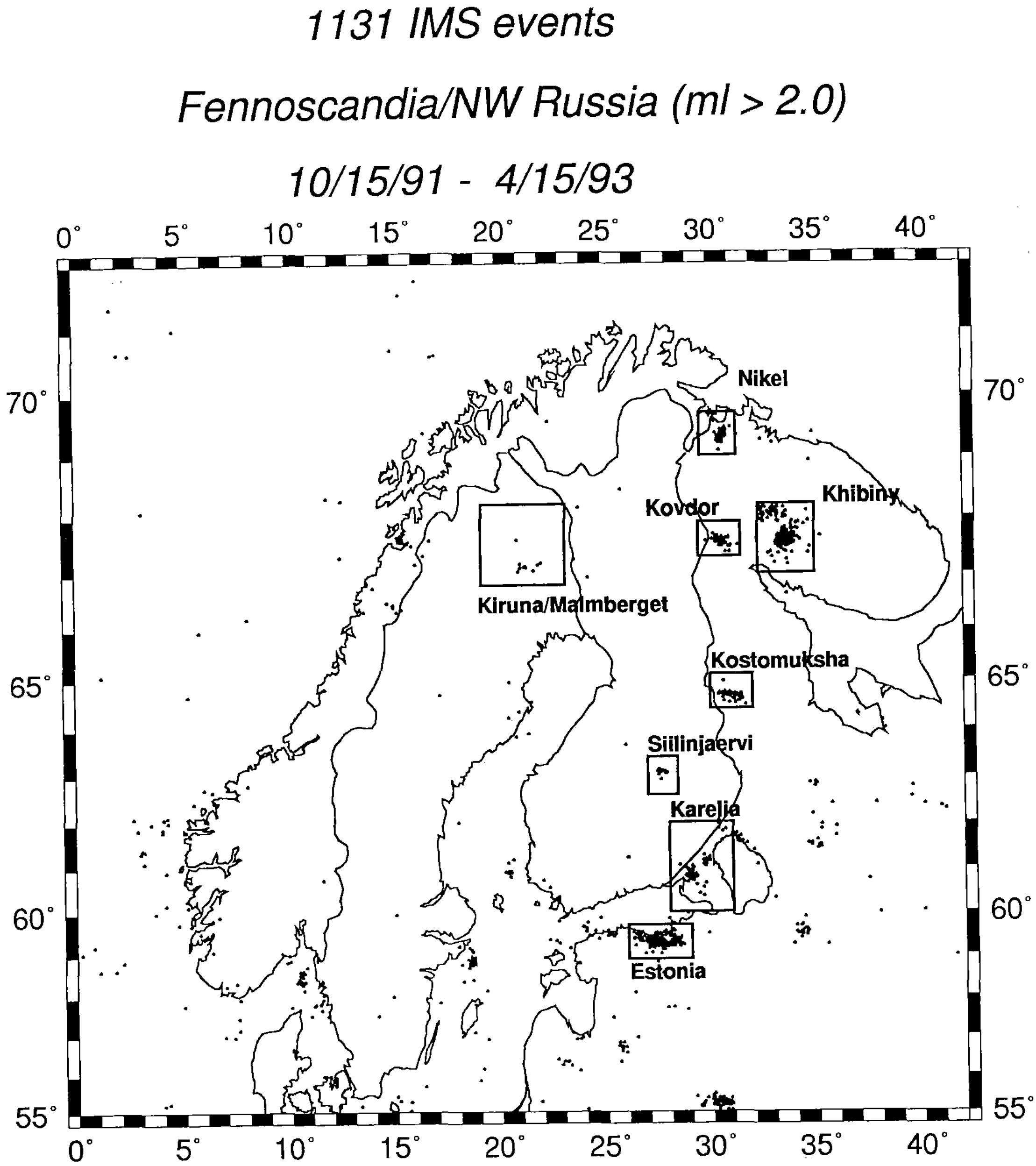

Fig. 7.1.4. Same as Fig. 7.1.2, but showing only events of $M_L > 2.0$. The total number of events is 1131 for the 18-month period.