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Frode Ringdal (ed.)

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6.2 Locating Seismic Events in Northern Eurasia

Introduction

As part of a project aimed at improving seismic monitoring capabilities under a CTBT, Kola Regional Seismological Centre (KRSC) and NORSAR are conducting a comprehensive study of seismicity, seismic wave propagation and seismic event location in the European Arctic. For Fennoscandia, excellent velocity models have previously been developed, and one such model is currently used at the prototype IDC (Bondar and Ryaboy, 1997). The velocity model in use at KRSC for the past several years (the Barents Model) is very similar to the model used at the prototype IDC, and is given in Table 6.2.1.

In this paper, we study the improvements that can be achieved when applying the Barents model to seismic events in the general northern Eurasia region, when compared to the IASPEI-91 model (Kennett, 1991).While the IASPEI-91 is an excellent average model for the entire globe, it is well known that regional velocity models can provide improvements in many cases. In particular, we will investigate whether the Barents model, which is known to give accurate locations in the Fennoscandian and NW Russia area, can be successfully applied to the more general northern Eurasia region.

Novaya Zemlya events

We have analyzed several seismic events at Novaya Zemlya, most of them nuclear explosions with quite accurate ground truth location. We have in fact, with the assistance of satellite imagery (Skorve and Skogan, 1992) determined very accurate reference locations for a set of these nuclear explosions. Our ground truth locations for these events, estimated to be within 1 km accuracy, are shown in Table 6.2.2. In the terminology used for the Calibration Database at the PIDC (Bondar and North, 1999) our location estimates would therefore qualify for the GT1 category.

Results from our relocation of five nuclear explosions recorded by the Barents regional network (Kremenetskaya and Asming, 1999) are shown in Figure 6.2.1. Only the four seismic stations in the Barents network (Amderma,Apatity, Barentsburg and Pyramiden) were used for this relocation. From this figure, it is seen that the errors when relocating these Novaya Zemlya nuclear explosions using the data from a regional seismic network with the Barents travel time model are all within about 10 km.

In addition, we have located the small m_b=3.8 nuclear explosion on 26 August 1984, using the Barents network (Fig. 6.2.2). This explosion was listed by Mikhailov et. al. (1996) and given an approximate location, based on NORSAR array observation only, by Ringdal (1997). The explosion was not reported by the ISC, and is not listed in Table 6.2.2. Our location is within the nuclear testing grounds, and is clearly better than the location given by Ringdal (1997). However, no ground truth is known to us for this event, and it is therefore difficult to verify the accuracy of our location. It appears nevertheless that the regional network in the Barents area will be capable of precise location of seismic events much smaller than the nuclear explosions listed in Table 6.2.2.

Events in northern Eurasia

Our next attempt was to study travel times in a much larger region, including the European and some of the Asian parts of the Former Soviet Union. We selected 12 seismic events which occured in FSU during 1984-1990 with known ground truth (See Table 6.2.3). The onset measurements have been taken form the ISC bulletins for all the stations situated closer than 30 degrees to the events (310 stations in FSU and surrounding countries). The travel paths for the station-event combinations are shown in Figure 6.2.3.

Results from comparing the observed P and S travel time to those predicted by the IASPEI-91 tables and the Barents model are shown in Figure 6.2.4. The P-wave travel times calculated using the events and stations mentioned above show considerable scattering, which is probably mainly due to some errors in timekeeping for analog stations in combination with occasional errors in the geographic coordinates of some stations (for former socialist countries). Nevertheless, some conclusions can be drawn :

1. In average, P-wave travel times are different both from the IASPEI-91 curve (about -2.0 sec) and from the Barents curve (about +0.5 sec);
2. Weighted average of IASPEI-91 and Barents curves (the 'COMBINED' travel time model) enables us to improve the event locations and avoid systematic bias in origin time estimation;
3. No systematic separation of travel times along different paths(indicating medium inhomogeneties) can be clearly noticed. This leads us to a preliminary conclusion that the same travel time curve can be used for the whole territory being considered ;
4. It is possible to use origin times estimates obtained by P-waves for calibrating travel times for other seismic phases;

Analysis of the S-wave travel times show even more scattering than for P-waves, and the observed times are situated in general between the IASPEI-91 and Barents curves. This might indicate that the S-arrival readings given in the ISC bulletins are not very accurate. In any case, it is clear that S-wave travel times require more careful calibration, probably using strong seismic events, with coordinates and origin times being estimated by the COMBINED model for P waves.

Events in north Karelia and the Kola Peninsula

The Kola Peninsula and North Karelia are regions of great mining activity and we systematically collect ground truth about mining explosions and mining rockbursts in these areas. Analyzing PIDC results for seismic events in the Kola Peninsula (Figure 6.2.5) we found out that location accuracy of PIDC has improved significantly in 1999 (errors about 15-20 km in comparison with 50-70 km in 1995-1998, with systematic bias almost absent). This is encouraging, and shows that the PIDC regional location calibration of this area has been successful.

A slightly different picture emerges for location of Kostomuksha (North Karelia) mining explosions. The average error is about 50 km with an almost absent systematic bias. This scatter is likely due to errors in onset time measurements (about 1.5-2 sec by our estimation).

PIDC detection capability in 1998-1999 is illustrated in Figure 6.2.6. This capability has deteriorated in comparison with previous years, probably due to changes in the GSETT-3 network configuration. Thus, in 1998 191 seismic events with magnitudes greater than 2.6 took place in the Kola Peninsula and only 16 of them have been located by PIDC. The numbers are about the same in 1999 : 213 events occurred and 15 located by PIDC.

Conclusions

All the observations mentioned above cause us to draw the general conclusion : to solve the problem of events location in our region (and, probably, in all of North-Western Russia) the main focus of study should be shifted from travel time table adjustments (which could already be considered to be done in a first approximation) to other important aspects such as improvements in onset time measurements and more reliable backazimuth computations, including perhaps additional parameters from acoustic systems.

KRSC has begun working on this problem. Thus, an acoustic system containing 3 digital barometers which have been installed in the Apatity Array in 1999 enabled us to calculate very accurate backazimuths to several seismic events of unknown nature occurring in areas where seismic activity has been observed. The existence of acoustic signals helped us to discriminate the events as open-pit explosions.

Additionally, we have started to develop a location algorithm based on the generalized beamforming (GBF) method (Ringdal and Kværna, 1989). Currently the algorithm has been checked for re-locating the 12 calibration events mentioned above by ISC data. Its results appeared to be about the same as when location is done by traditional method. But the GBF algorithm has several advantages: it enables easy automatic removal of wrong onsets and permits including any kinds of additional parameters in the form of weights of grid cells.

One of our main tasks remains the collecting of ground truth data in northern Eurasia. With the help of Valery Nikulin, Geological Survey of Latvia we have obtained ground truth data on explosions in the Baltic countries. These data are promising for improving location in our area.

Elena O. Kremenetskaya, KRSC
Vladimir E. Asming,KRSC
Frode Ringdal, NORSAR

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Table 6.2.1. Barents Regional Velocity Model

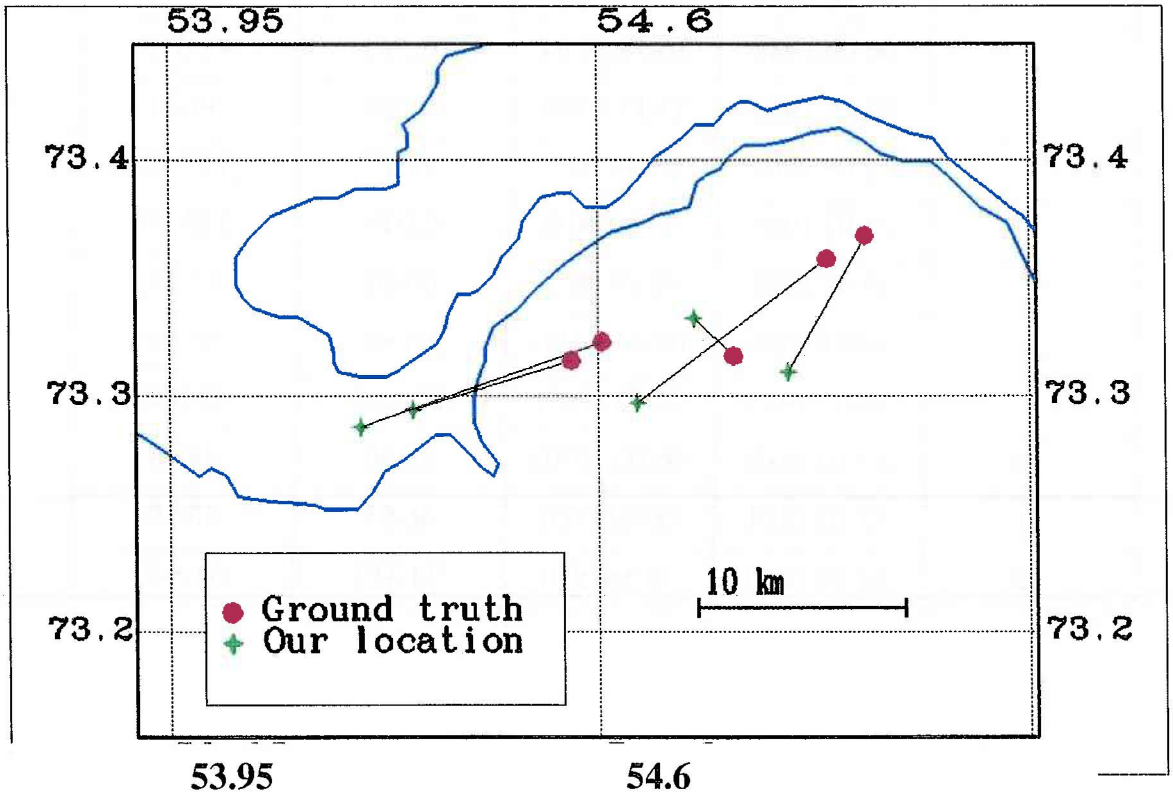
Depth (km)	V_P (km/s)	V_S (km/s)	Comment
0-16	6.20	3.58	
16-40	6.70	3.87	
40-55	8.10	4.60	
55-210	8.23	4.68	
>210			Same as IASPEI-91

Table 6.2.2. Ground truth data (GT1) for Novaya Zemlya nuclear explosions

No.	Date	Lat (Deg)	Lat(Min)	Lon(Deg)	Lon(Min)
1	18 Sep 64				
2	25 Oct 64	73	22.6	55	9.9
3	27 Oct 66	73	23.0	54	50.5
4	21 Oct 67	73	23.3	54	49.6
5	7 Nov 68	73	23.4	55	52.0
6	14 Oct 69	73	23.4	54	48.2
7	14 Oct 70	73	18.0	55	1.6
8	27 Sep 71	73	23.3	55	54.2
9	28 Aug 72	73	23.1	54	52.0
10	12 Sep 73	73	18.9	55	2.8
11	29 Aug 74	73	23.6	54	56.0
12	23 Aug 75	73	19.9	54	42.3
13	21 Oct 75	73	18.4	55	0.2
14	29 Sep 76	73	21.6	54	51.9
15	20 Oct 76	73	23.9	54	51.0
16	1 Sep 77	73	19.6	54	37.7
17	9 Oct 77	73	23.4	54	50.0
18	10 Aug 78	73	17.9	54	49.4
19	27 Sep 78	73	20.2	54	42.0
20	24 Sep 79	73	19.9	54	40.1
21	18 Oct 79	73	19.1	54	46.3
22A	11 Oct 80	73	18.3	54	48.9
23	1 Oct 81	73	18.3	54	47.1
24	11 Oct 82	73	19.9	54	36.2
25	18 Aug 83	73	21.5	54	56.7
26	25 Sep 83	73	19.2	54	34.6
27	25 Oct 84	73	21.6	54	58.7
28	2 Aug 87	73	19.4	54	36.4
29	7 May 88	73	18.9	54	33.6
30	4 Dec 88	73	22.1	55	0.2
31	24 Oct 90	73	19.0	54	48.3

Table 6.2.3. Calibration events used in this study

No.	Date	Origin time	Latitude (N)	Longitude (E)
1	28.05.1990	02.41.27	55.17	58.72
2	22.08.1988	16.20.00.07	66.28	78.491
3	06.09.1988	16.19.59.94	61.361	48.092
4	03.10.1987	15.15.00.03	47.60	56.20
5	12.08.1987	01.30.00.5	61.45	112.80
6	24.07.1987	02.00.00.0	61.45	112.80
7	19.04.1987	04.00.00.1	60.60	57.20
8	19.04.1987	04.04.59.98	60.80	57.50
9	18.07.1985	21.15:00.29	65.994	41.038
10	27.10.1984	06.00.00.10	46.90	48.15
11	27.10.1984	06.05.00.0	46.95	48.10
12	24.10.1990	14.58.00.0	73.317	54.805



NZ nuclear explosions located by regional stations and BARENTS travel time model.

Fig. 6.2.1. *Results from locating five nuclear explosions at Novaya Zemlya using the Barents regional seismic network. The ground truth locations (from Table 6.2.2) are shown for comparison. Note that all our locations are accurate to within approximately 10 km.*

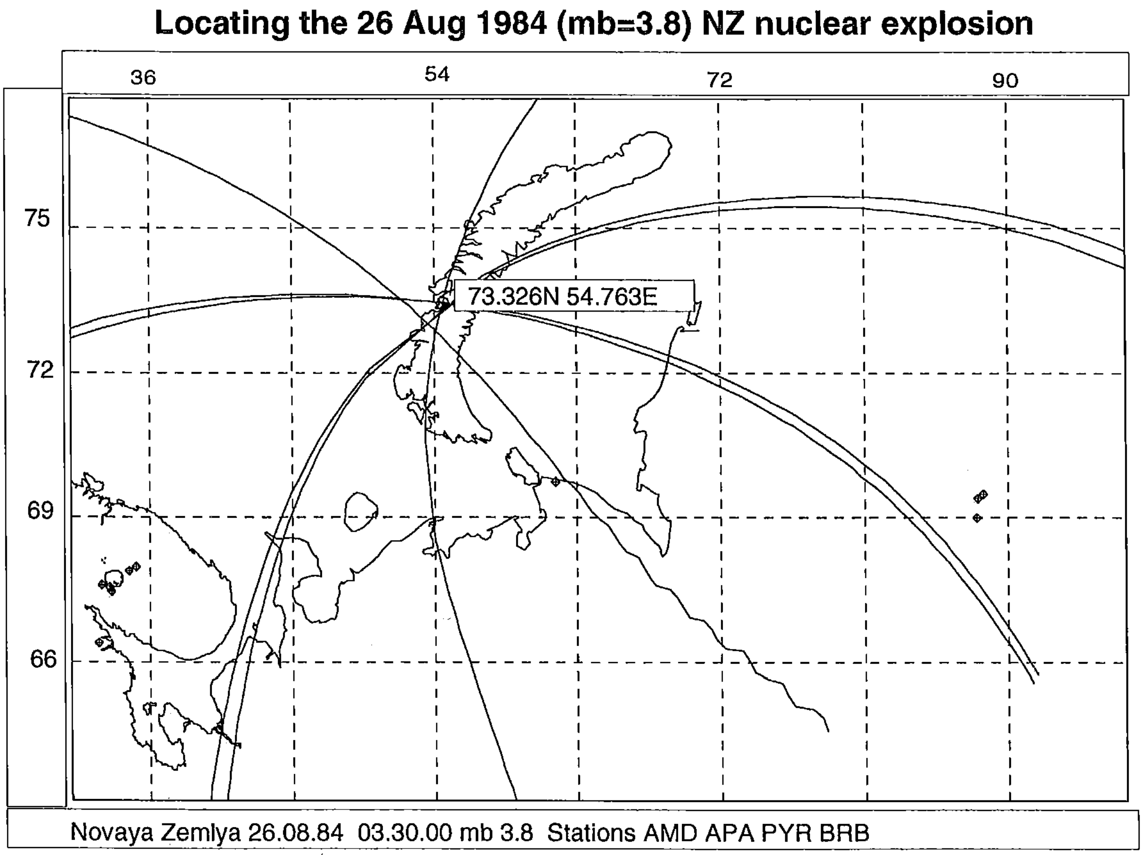


Fig. 6.2.2. *Results from locating the small Novaya Zemlya nuclear explosion (m_b=3.8) on 26 August 1984, using the stations of the Barents network.*

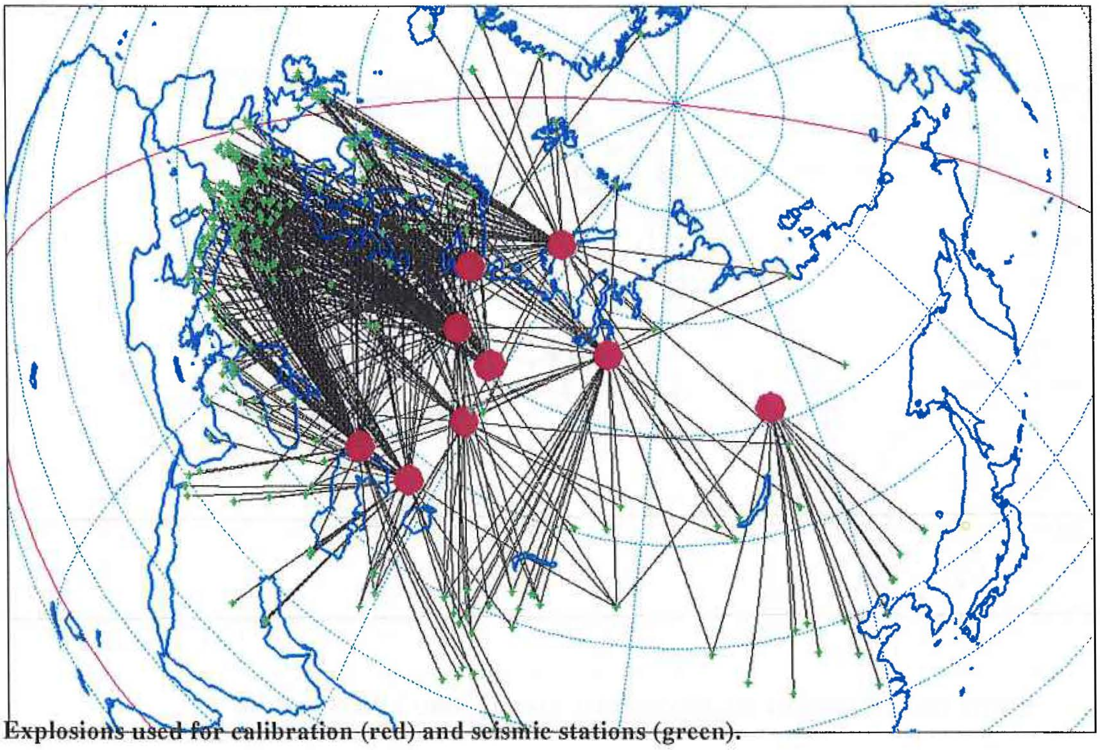


Fig. 6.2.3. *Station-event coverage paths for the 12 calibration events listed in Table 6.2.3.*

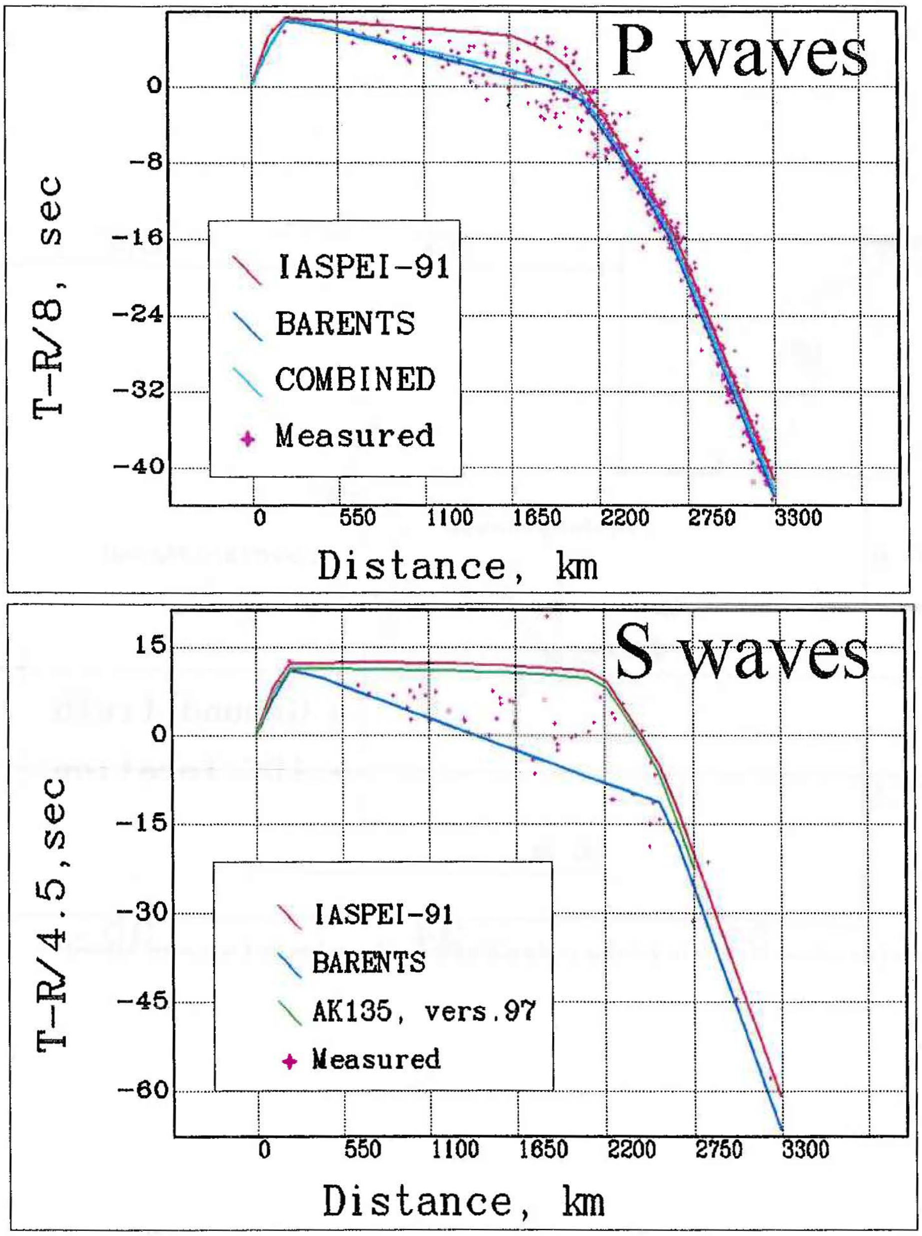


Fig. 6.2.4. *Observed travel times for P and S phases for the calibration event data set. The predicted travel-time curves for the IASPEI-91 model and the Barents model are shown for comparison. We also show the AK135 model (97 version) for the S-phases, and our calculated Combined model, which turns out to be very close to the Barents model for P-phases.*

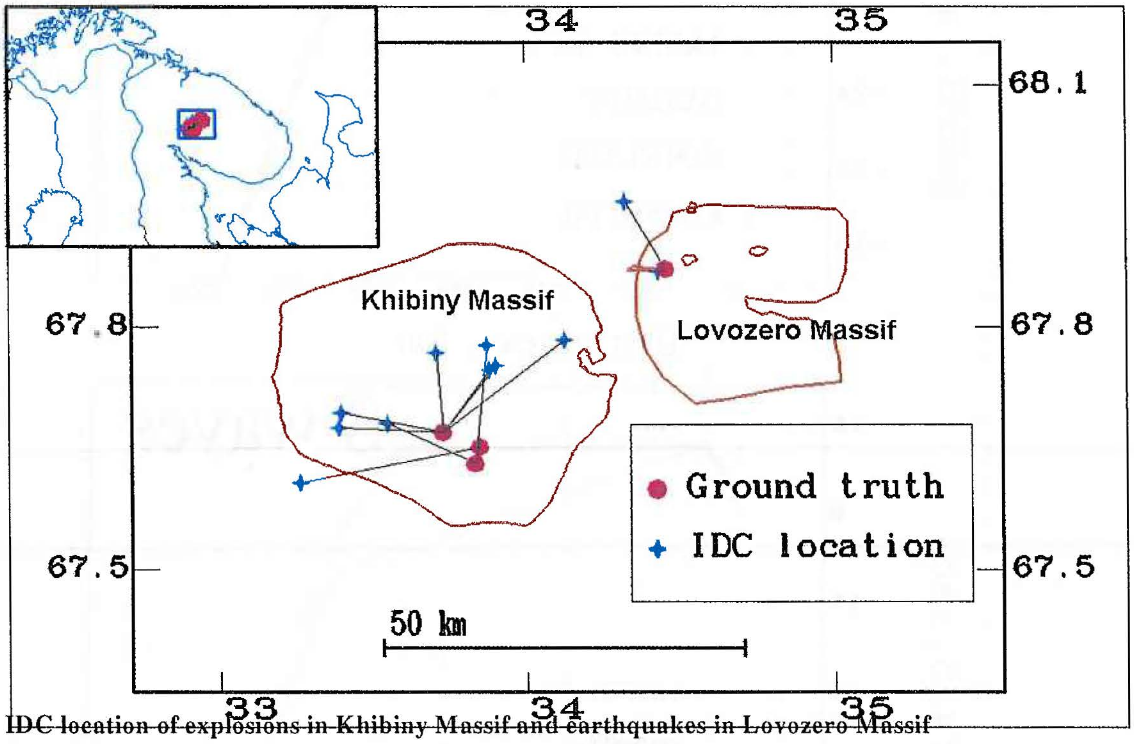
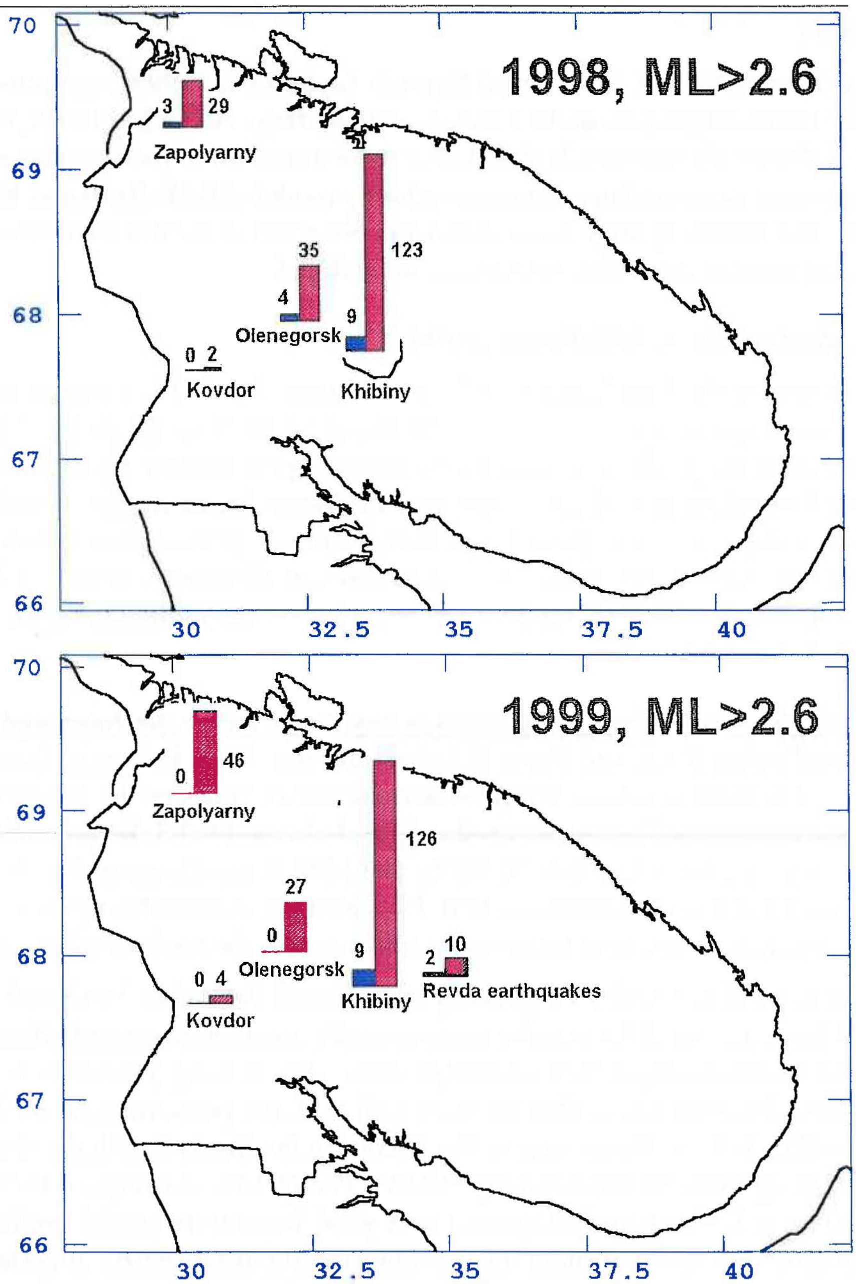


Fig. 6.2.5. *PIDC location errors for Khibiny events during 1999. Ground truth locations for these eventshave been provided by KRSC. The location errors are about 15-20 km, which is much better than for previous years.*



Numbers of events : detected by IDC (blue columns)
true numbers (red columns)

Fig. 6.2.6. *Illustration of event detectability for the Kola Peninsula of the PIDC Reviewed Event Bulletin (REB) for the years 1998-99. The histograms show the number of events exceeding magnitude (m_b) 2.6, as reported in the NORSAR and KRSC regional bulletins, and the number of events located by the PIDC at each of five main sites. The percentage of such events in the REB is much lower than for previous years.*