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6.2 Seismic Location Calibration for the Barents Region

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Abstract

A crustal velocity model has been developed for Fennoscandia, the Baltic shield and adjacent areas. This model represents a simplified average of various models developed for parts of this region. We show that P-wave travel times calculated with this model provide an excellent fit to observations at the Fennoscandian, KRSC and IRIS station networks for a set of seismic events with known or very well-constrained locations. The station-event paths cover large parts of Western Russia and the Barents Sea, thus indicating that this model, which we denote the Barents model, is appropriate for this entire region. We show by examples that significant improvements in event location precision can be achieved compared to using the IASPEI model. We finally use the Barents model to calculate locations of some recent small seismic events in the Novaya Zemlya region of interest in a CTBT monitoring context.

Key Words: Location, Crustal models, Travel-times, Calibration

Introduction

Kola Regional Seismological Centre (KRSC) of the Russian Academy of Sciences have for many years cooperated with NORSAR in the continuous monitoring of seismic events in North-West Russia and adjacent sea areas. This work has been based on a network of sensitive regional arrays which has been installed in northern Europe during the last decade in preparation for the global seismic monitoring network under a comprehensive nuclear test ban treaty (CTBT).

KRSC began its seismic network processing in 1982. Initially, this was done primarily by processing data from the KRSC network of seismological stations, but in recent years the analysis has been supplemented with data from IRIS stations (KBS, LVZ, KEV, ARU, ALE, NRI etc.) and the Scandinavian seismic arrays (ARCESS, SPITS, FINESS, HFS, NORESS) for analyzing of the most interesting events.

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 Barents region. For Fennoscandia, excellent velocity models have previously been developed, and one such model is currently used at the prototype IDC. 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 study, we have studied the improvements that can be achieved when applying the Barents model to seismic events in NW Russia and the Barents Sea region, when compared to the IASPEI 91 model.

Data Base

As a data base for this study we have selected seven well-recorded events in the region, as listed in the first part of Table 6.2.2. For three events, we have been able to obtain ground truth information, as specified in the table. This includes the calibration explosion in Khibiny on 29 September 1996 (Ringdal et al, 1996) and the nuclear explosion near Arkhangelsk on 18 July 1985, for which both the exact location and origin time is known. The Solikamsk event on 5

January 1995 was caused by a collapse associated with a mine, and we have provided an exact location. For four events in Table 6.2.2 we have recomputed the location using available stations in the GSETT-3 network, the Kola network and the IRIS network.

In addition to these seven events, we have provided in the last part of Table 6.2.2 ground truth locations for two events on 28 May 1990 further south in the Ural Mountains. These two events are associated with rockbursts and were large enough (m_b=4.4) to be recorded teleseismically. These events are listed for reference purposes, and were not used in the analysis described in this paper. We consider that this information may be important for future studies aimed at developing appropriate velocity models for the southern Urals.

Station Network

The regional seismic network in the Kola Peninsula currently comprises 7 seismic stations, as described by Kremenetskaya and Asming(1999). For the events during 1995-96 in the present study, only those stations with digitally recording equipment have been used. In addition, several stations in Fennoscandia, some IRIS stations, as well as stations contributing to the PIDC have been used. We have only used data from stations within an epicentral distance of approximately 30 degrees for each event, and concentrated on station-epicenter combinations that cross parts of the Barents Region. The station network used in this study together with the station-event paths is shown in Fig. 6.2.1.

Barents Velocity Model

The Barents velocity model in Table 6.2.1 is a crustal model that has been in use at KRSC for many years. It represents a simplified average over various models developed for parts of Fennoscandia and NW Russia. Much of these developments are based upon profiles from explosion seismology in this area. We also note that the Barents model is similar (although not identical) to that described by Mykkeltveit and Ringdal (1981), and it is also quite close to the model currently used at the prototype IDC.

In the data analysis of this paper, it is an important point to make that the model is derived independently of the data. Therefore, the fit of the data to the model will be a true validation of how the model works in practice for this region.

Data Analysis

Using the Barents model, we have located all the reference events apart from those with ground truth information, and calculated the estimated P and S-phase arrival times using the Barents model. The results are shown in Figs. 6.2.2 and 6.2.3, both for the ground truth events (triangles) and the calculated solutions (circles). The Barents model as well as the IASPEI-91 model are shown for comparison. It is evident that the Barents model provides the best fit for the ground truth data, and that this model in fact represents the data very accurately. By definition, the calculated data points will fit the Barents model better than the IASPEI model, but more importantly, it seems to be a good consistency with the Barents model over the entire set of observations, both for P and S phases. Our results therefore indicate the validity of the Barents model for the entire region under consideration.

Location Experiments

We have used the two models to calculate epicenters for those events with known ground truth information, and compared the results. Two examples are shown in Figs. 6.2.4 and 6.2.5. For the 18 July 1985 Arkhangelsk explosion (Fig. 6.2.4), the location errors were 17.2 km (IASPEI 91 model) and only 4.4 km (Barents model). For the 5 January 1995 event (Fig. 6.2.5), the errors were 19.5 km (IASPEI 91 model) and 8.5 km (Barents model). It is also noteworthy (although not shown on the figures) that the USGS/ISC global network location errors for both events were about 10 km, thus the regional model shows location improvement in spite of using only a fraction of the available stations.

To validate the model further we have re-located several previous seismic events for which we do not have ground truth, but which are located very accurately by the joint hypocentral determination method. (see Table 6.2.3). As can be seen from this table, and further illustrated in Fig. 6.2.6, the locations by the regional network are within 5-10 km of the locations obtained by joint hypocentral determination (JHD) using world-wide data.

The model therefore seems to be quite adequate for event location in the Barents region. In addition, the documented consistency with precise global network locations is especially important since we are able to use the network to locate regional events far smaller than those which can be detected teleseismically. For example, the KRSC network was the only network with sufficient data to locate reliably the smallest recorded nuclear explosion on the Novaya Zemlya test site (m_b=3.8) on August 26, 1984 (Mikhailov et. al., 1996). The result is shown in Fig. 6.2.7. Our estimated epicentral coordinates of this explosion are 73.326N, 54.763E, thus placing the event within the group of explosions shown in Fig. 6.2.6. While we have no other network solution with which to compare our result, we believe this explosion to be rather accurately located.

We have finally used the Barents model to calculate locations of some recent small events near Novaya Zemlya, of interest in seismic monitoring. These events, which was not included in the paper by Ringdal (1997), are shown in Figs. 6.2.8-6.2.10 and comprise a small seismic event near Novaya Zemlya on 23 February 1995 and the two seismic events in the Kara Sea on 16 August 1997. While we do not have ground truth reference for any of these events, we observe that our location of the first event on 16 August 1997 is close to the location published by several other authors (e.g. Ringdal et al, 1997). The second event on that day is less accurately located, since it was much smaller. Our estimated location, based on three station, is about 30 km East of the first event. However, based on a detailed analysis of the signals recorded at Spitsbergen and Amderma, we believe that the two events that day were approximately co-located. The event on 23 February 1995 has to our knowledge not been reported before, and it is difficult to ascertain the accuracy of this location. We note that in all of these location experiments, we have restricted the solution to zero depth. It is interesting to notice that both the 23 February 1995 event and the first event on 16 August 1997 had estimated origin times very close to the minute (using the Barents model and a restricted (zero) depth). This might indicate a man-made source, but we do not wish to speculate on this issue.

Effects of Reading Errors

In practical IDC operation, the location accuracy will be determined not only from the quality of the velocity model, but also from the quality and accuracy of the phase readings used in the location algorithm. We have carried out a preliminary study, using a set of 52 Khibiny explosions detected and located by at least 4 stations (with P detections) in the GSETT-3 network. All 52 events have known ground-truth location. We used phase readings exactly as provided in the PIDC bulletin (REB). Most of these readings are based on automatic timing, and have in many cases been adjusted by the PIDC analyst. In some cases, the analyst have added phase readings not detected automatically.

For each event, we compared locations using the IASPEI model with locations based on the same observations, but with the Barents model. To obtain a simple measure of the results, we calculated the percentage of these 52 events that were located within 18 km of the true epicenter. It should be noted that a circular area of 18 km represents an area of approximately 1000 square km, which is a generally accepted target for location precision in the GSETT-3 network.

It turned out that 21% of the locations using the IASPEI 91 model had errors of less than 18 km, whereas the number of such events was increased to 37% when using the Barents model for the same data. However, we observed that the S-residuals were rather large with the Barents model, and therefore attempted to locate the events using the P-phase data only (with the Barents model). This resulted in 62% of the events being located with an error of less than 18 km, which is a significant improvement over both of the other approaches. It appears from this result that the S-phase readings used in the GSETT-3 bulletins might be less accurate than desirable. The reasons for this is unknown, but will be further investigated.

Conclusions

We conclude that the Barents model is appropriate not only for Fennoscandia, but for the entire Barents region from Spitsbergen to Novaya Zemlya, and also for northwestern Russia. Use of this model would be expected to improve location accuracy considerably compared to the use of IASPEI-91, especially when both P and S phases are used in the location procedure.

We have also observed in this paper that in the absence of a well-calibrated velocity model, it might seem preferable to make epicenter estimates based on P-phases only, since these location estimates are less sensitive to model errors than locations based on a combination of P and S phases. However, it must be noted that the S-phases, even in the absence of a good velocity model, do place important constraints on the distance to the epicenters. The use of S therefore in many cases reduces the likelihood of gross error, which might occur if there are only few P-readings with poor azimuthal distribution. We plan to conduct more detailed studies of this problem in the future.

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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: Calibration Events — Barents Region

Region	Date	Origin time	Latitude (N)	Longitude (E)
Arkhangelsk**	18.07.1985	21.15:00.3	65.9939	41.0381
Solikamsk*	5.01.1995	12.46:02.1	59.59	56.80
NW from Spitsbergen	26.04.1995	8.55:59.9	85.128	8.58
Zapolyarny	7.06.1995	11.09:42.7	69.43	30.835
Barents Sea	11.06.1995	19.27:14.0	75.745	34.727
Novaya Zemlya	13.06.1995	19.22:39.0	75.175	56.627
Khibiny**	29.09.1996	6.05:46.19	67.675	33.728
Additional ground truth information:				
Ural Mountains*	28.05.1990	00.35:50.0	55.17	58.72
Ural Mountains*	28.05.1990	02.41:27.0	55.17	58.72
) Known location* *)Known location and origin time*				

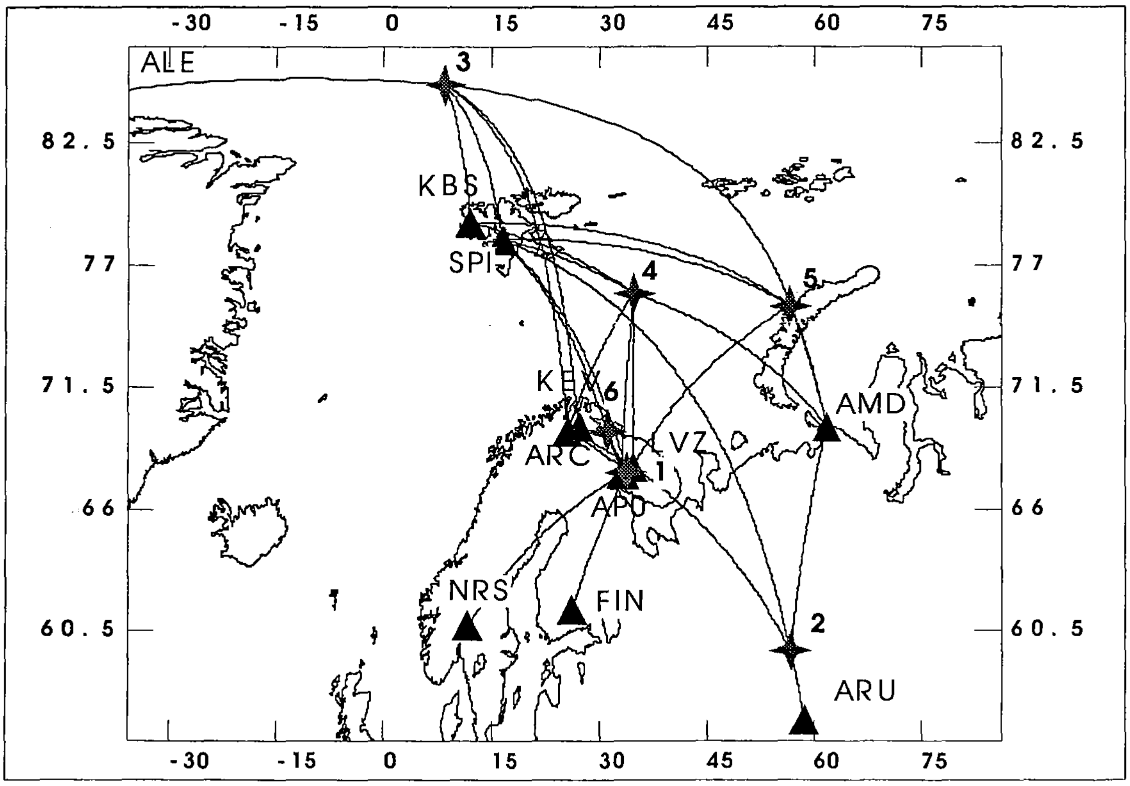


Fig. 6.2.1. Map showing the calibration events and the station-event paths forming the data base for this study.

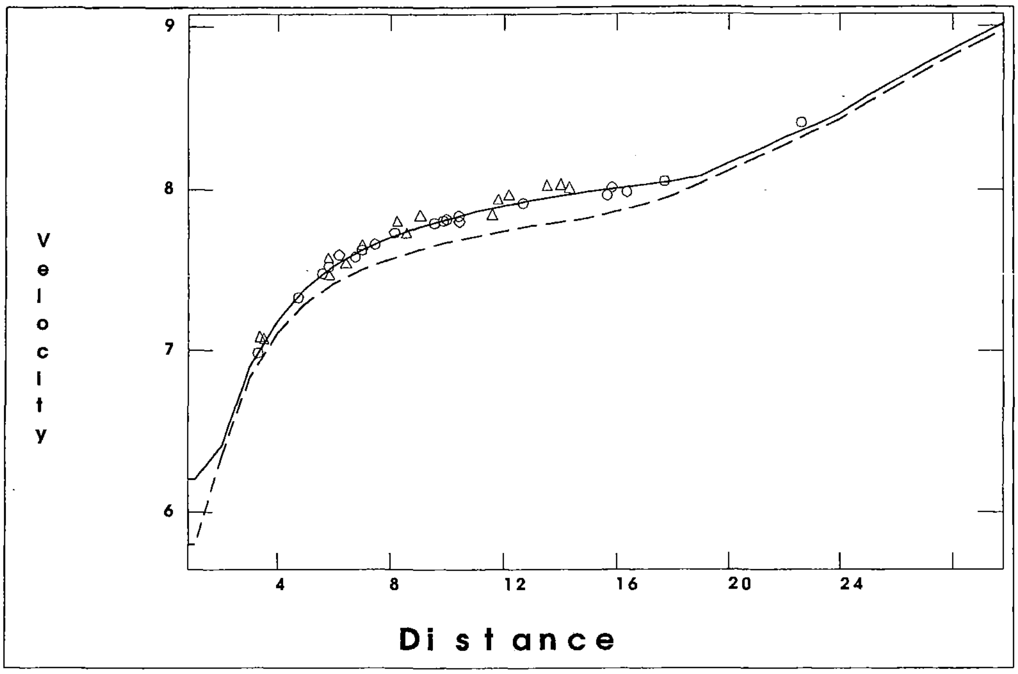


Fig. 6.2.2. Observed P-wave velocity as a function of epicentral distance for the events in the data base. Ground truth observations are shown as triangles, whereas the circles represent observations using calculated epicenters. The Barents model (solid line) and the IASPEI-91 model (stippled line) are shown for comparison. See text for details.

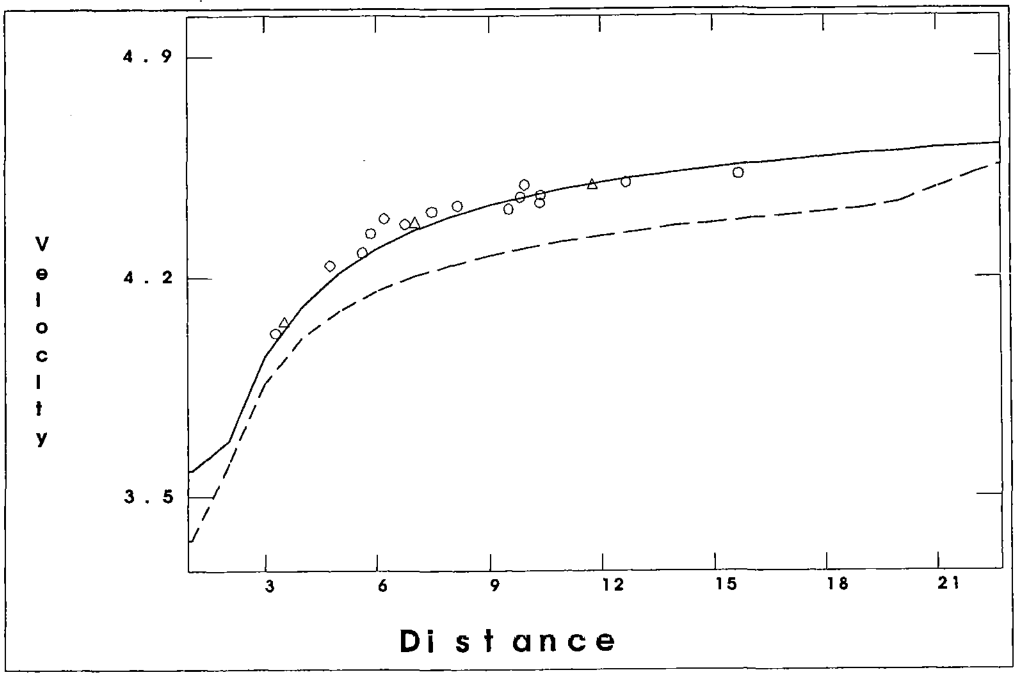
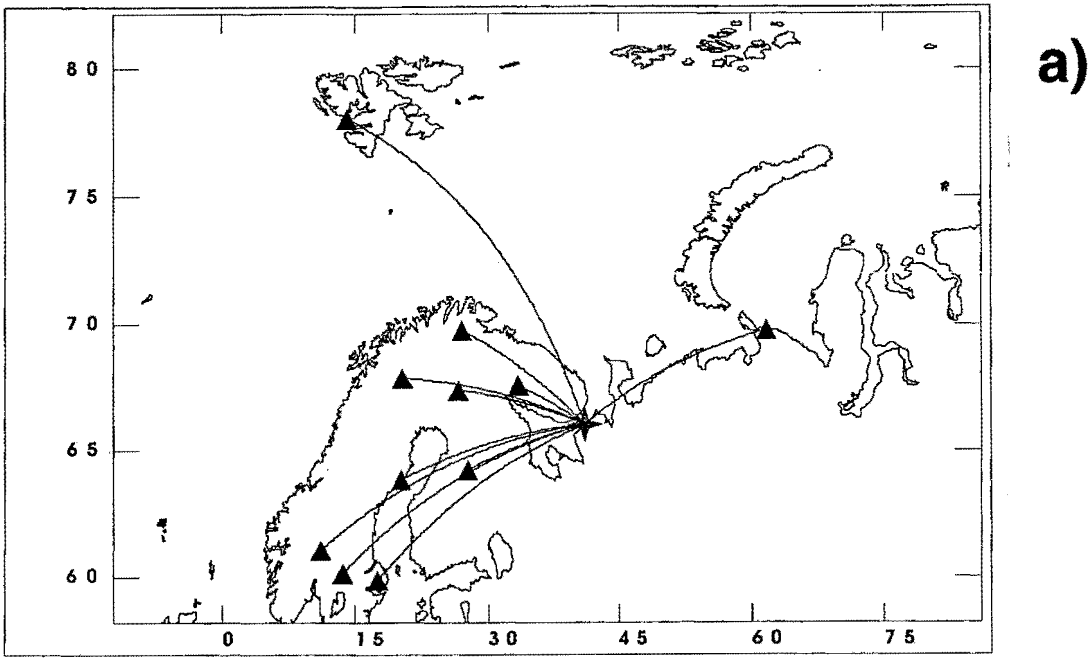


Fig. 6.2.3. Observed S-wave velocity as a function of epicentral distance for the events in the data base. Ground truth observations are shown as triangles, whereas the circles represent observations using calculated epicenters. The Barents model (solid line) and the IASPEI-91 model (stippled line) are shown for comparison. See text for details.



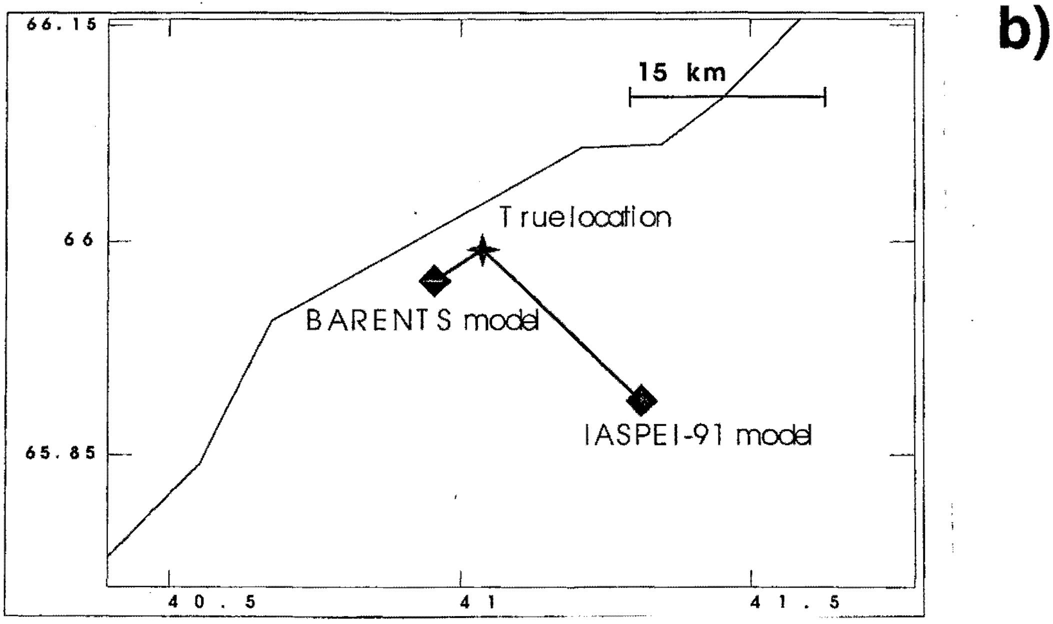


Fig. 6.2.4. Location comparison using the Barents and IASPEI-91 model for the 18.07.85 nuclear explosion near Arkhangelsk. The stations used in the location procedure are shown separately.

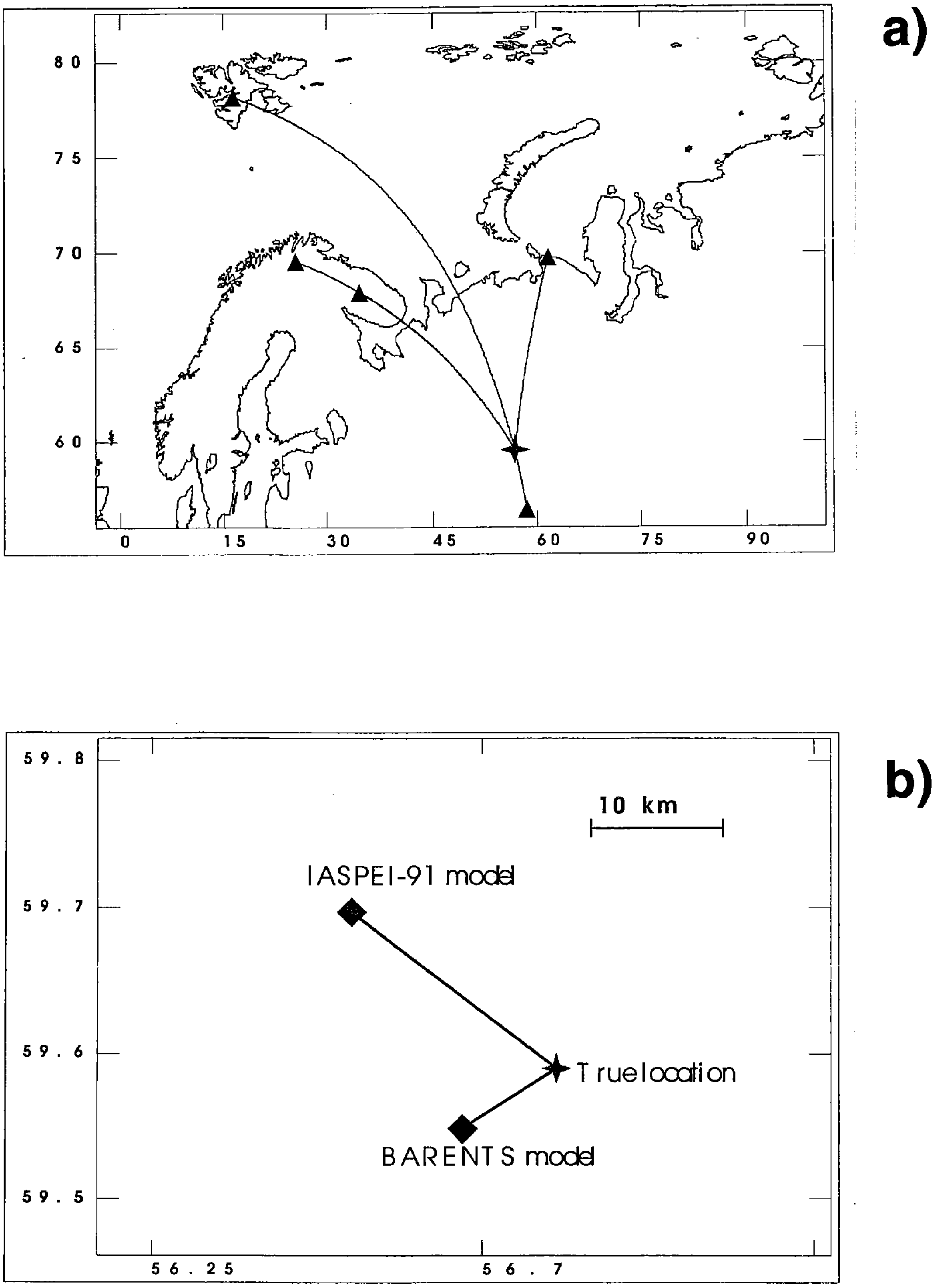


Fig. 6.2.5.Location comparison using the Barents and IASPEI-91 model for the 05.01.95 mine collapse near Solikamsk. The stations used in the location procedure are shown separately.

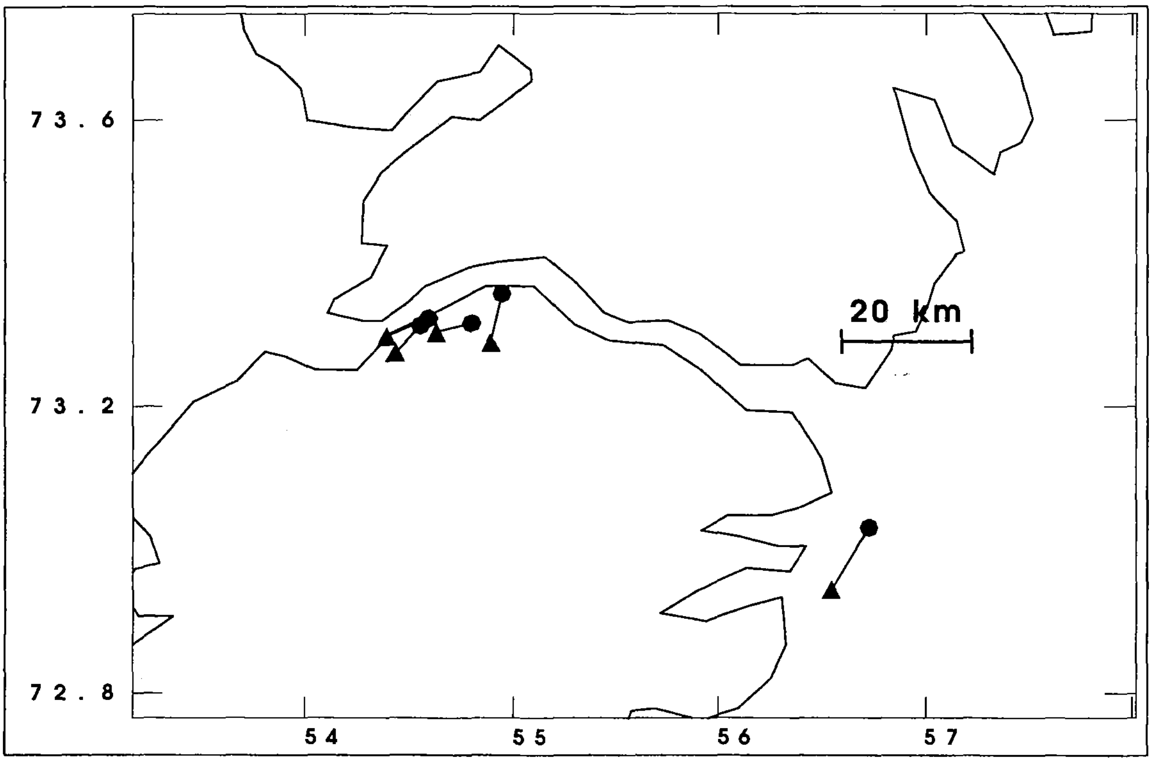


Fig. 6.2.6. Location comparison of JHD epicenter estimates using a global network and regional location estimates using the Barents model with a regional network. The figure corresponds to the data in Table 6.2.3.

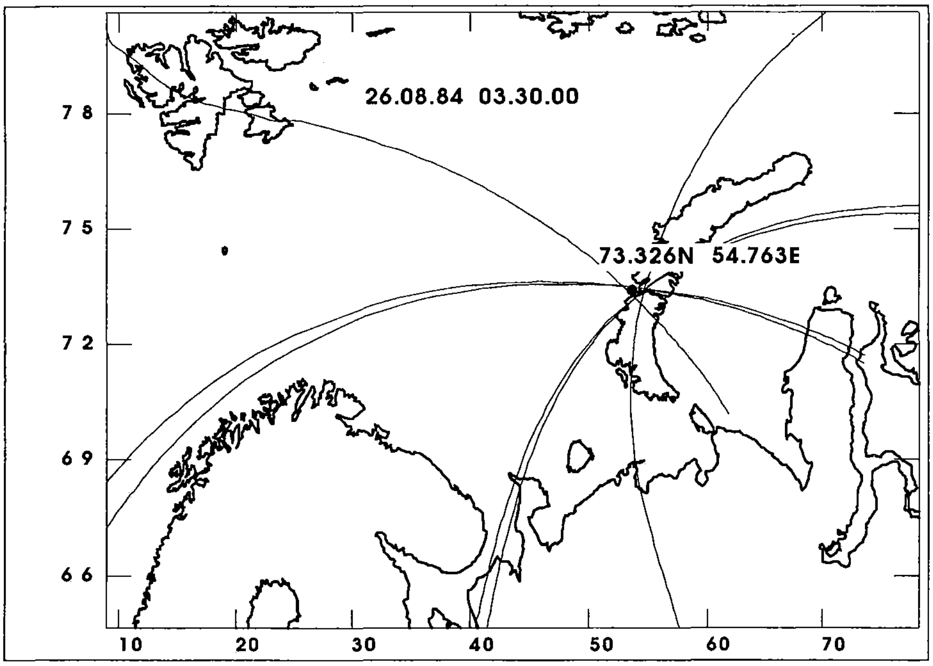


Fig. 6.2.7. Location of a small nuclear explosion on Novaya Zemlya, using the Barents model with a regional network.

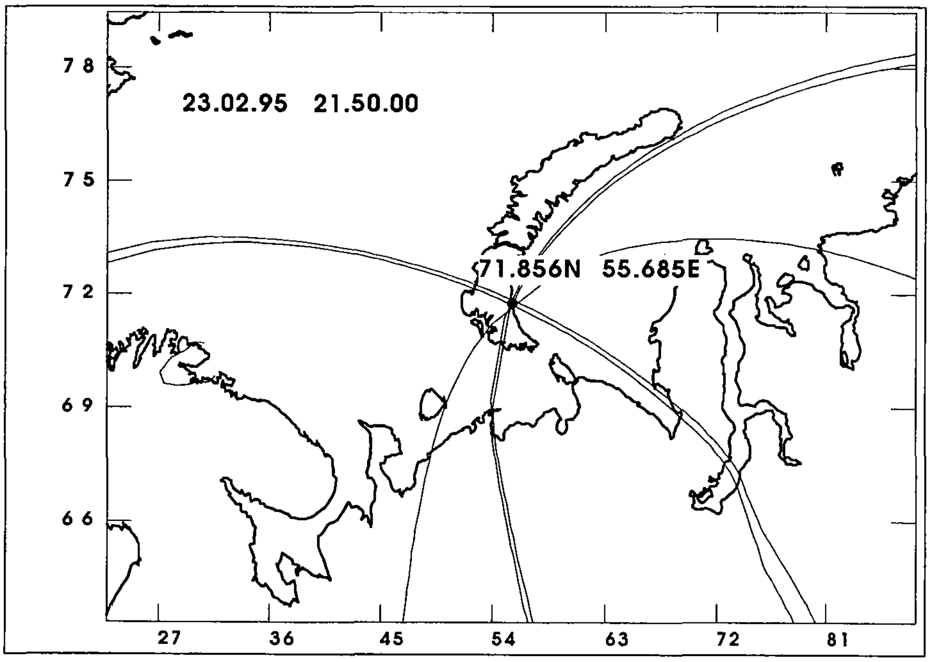


Fig. 6.2.8. Location of a small seismic event on 23 February 1995, using the Barents model with a regional network.

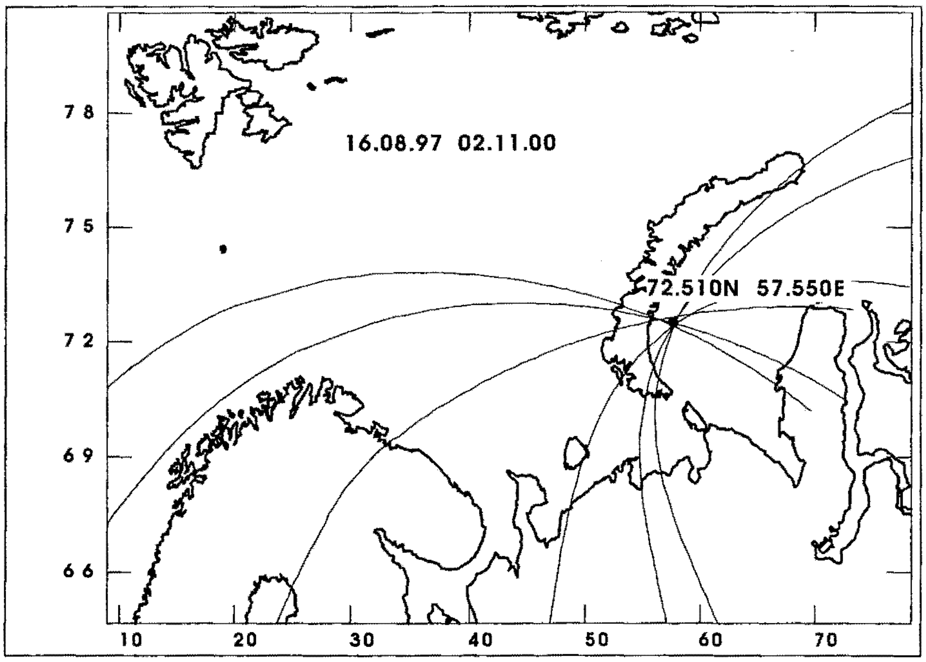


Fig. 6.2.9. Location of the first seismic event on 16 August 1997, using the Barents model with a regional network.

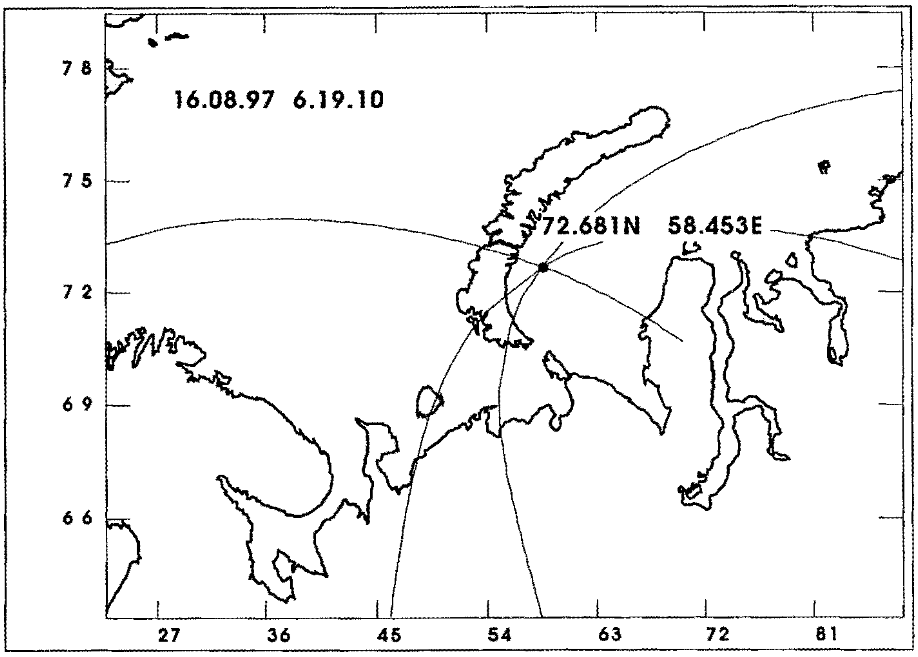


Fig. 6.2.10. Location of the second seismic event on 16 August 1997, using the Barents model with a regional network.