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7.5 Study of seismic travel-time models for the Barents region

Introduction

As part of a project aimed at improving seismic monitoring capabilities under a CTBT, NORSAR and Kola Regional Seismological Centre (KRSC) have begun a comprehensive study of seismicity, seismic wave propagation and seismic event location in the Barents region. This paper gives initial results from this research program.

As is well known, accurate location of seismic events with a regional network requires detailed knowledge of the propagation characteristics of seismic waves in the region. For Fennoscandia, an excellent velocity model (the NORSAR model) has previously been developed, and is being used at both KRSC and NORSAR.

An example of the importance of choosing the correct regional velocity model was given by Ringdal (1997) for the 13 January 1996 event near Novaya Zemlya. In the present study, we have applied the NORSAR model to the general Barents region, including Western Russia, and compared it with the IASPEI 91 model which is currently used by the GSETT-3 IDC. The purpose has been to investigate to which extent the NORSAR model is adequate for this entire region.

The station network

The regional seismic network in the Kola Peninsula currently comprises 7 seismic stations, as described by Kremenetskaya et. al. (1995). For 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 GSETT-3 IDC 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 stations are listed in Table 7.5.1, and shown on Figure 7.5.1.

Data base

We have selected six well-recorded events in the region, including the calibration explosion in Khibiny on 29 September 1996. For this one event the exact location and origin time is known, whereas for the other events we have recomputed the location using available stations in the GSETT-3 network, the Kola network and the IRIS network.

In order to minimize the effect of unknown velocity structure, we have used only P-readings in the relocation procedure. This method is less sensitive to regional variations than using a combination of P and S, because a shift in P-velocities will cause a shift in origin time, without influencing significantly the epicentral estimate. In fact, the IASPEI-91 model and the NORSAR model gives almost identical location estimates when using P-waves only. All the events are either near-surface (explosions) or shallow earthquakes, and the depths have been constrained to 0 in the location procedure.

The estimated locations, using the NORSAR P-wave travel time model, are given in Table 7.5.2. The paths from each recording station to the epicenter of each of the six events are shown in Figure 7.5.2. It can be seen that the Barents sea is well covered, and some of the paths cover parts of Fennoscandia/NW Russia as well.

Travel time analysis

After locating the events, we have compared predicted and actual P and S-wave travel times, using both models. Our approach has been, for each model, to use the estimated epicenter and origin time based on the P-data for that model, and then compare the predicted and observed S-arrivals.

Figure 7.5.3 shows the results for the IASPEI model. The P-wave fit is naturally good, because the P-waves have been used to determine the origin time and epicenter of each event. However, the observed S-wave velocities are consistently higher than those predicted by this model.

Figure 7.5.4 shows corresponding results for the NORSAR model. The P-wave fit is again good for the same reason as outlined above. In addition, the S-wave data now shows excellent fit between the predicted and observed arrivals.

We conclude that the NORSAR 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.

As an illustration of the difference between the two models, we will present an example, namely, the 13 June 1995 event near Novaya Zemlya. This is Event 5 in our data base, and has been discussed in detail by Ringdal (1996). Waveform plots and predicted phase arrivals for this event are shown in Figure 7.5.5 (for the IASPEI model) and 7.5.6 (for the NORSAR model). For each figure, the predicted P-arrivals are consistent with the P-onsets. This is a consequence of using the P-arrivals for the respective models to estimate the location and origin time. We note, however, that while the theoretical S-wave arrivals are very accurate for the NORSAR model, they are far too late for the IASPEI model.

Discussion

The first event was the calibration explosion on September 29, 1996, which has an accurately known location and origin time (Ringdal et al, 1996). We were therefore able to estimate accurate travel times and velocities for P and S. (see Table 7.5.3).

There are some interesting observations to be made from this table that will be subjected to further study. For example, the local velocity structure near Khibiny is highly azimuth-dependent, with low velocities to the north (Lovozero) and high velocities to the south (PLQ). This is also evident from the figures previously shown, which do not provide good fits to any of the two models at small distances.

Also, from Figure 7.5.3, the velocities across the western part of the Barents shelf appear to be even higher than those predicted by the NORSAR model. Admittedly, the difference is small compared to the difference between NORSAR and IASPEI, but it might still be a subject for further investigations.

Of special interest is to determine whether the NORSAR velocity model can be applied to improve the event locations made by the GSETT-3 IDC for the Barents Region. 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. For each event, we compared the IDC locations (using the IASPEI model) with locations based on the same observations, but with the NORSAR 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.

As it turned out, 21% of the IDC locations had errors of less than 18 km, whereas the number of such events was increased to 37% when using the NORSAR model for the same data. However, we observed that the S-residuals were rather large with the NORSAR model, and therefore attempted to locate the events using the P-phase data only (with the NORSAR 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 (see Fig. 7.5.7).

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.

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 7.5.1. List of seismic stations used in this study

Name	Latitude	Longitude
APA (Broadband)	67.568N	33.388E
PLQ	66.410N	32.750E
ARCESS (Array)	69.534N	25.511E
Amderma (Array)	69.742N	61.655E
NORESS (Array)	60.735N	11.541E
ARU	56.430N	58.560E
KBS	78.926N	11.942E
ALE	82.503N	62.350W
LVZ	67.898N	34.651E
KEV	69.755N	27.007E
SPITS (Array)	78.180N	16.350E
FINESS (Array)	61.440N	26.080E
APO (Array)	67.603N	32.994E

Table 7.5.2. List of seismic events used in this study. The locations are estimated from P-phases using the NORSAR velocity model. For Event 1, the true location is given in the comment field.

No	Date	Origin time	Latitude	Longi-tude	Comment
1	29.09.1996	06.05:46.19	67.677N	33.733E	Explosion in Khibiny (at 67.675N 33.728E)
2	05.01.1995	12.46:01.65	59.561N	56.566E	Solikamsk
3	26.04.1995	08.55:59.33	85.088N	8.332E	NW from Spitsbergen
4	11.06.1995	19.27:13.34	75.74N	34.79E	Barents sea
5	13.06.1995	19.22:38.36	75.177N	56.528E	Near Novaya Zemlya
6	07.06.1995	11.09:41.57	69.485N	30.992E	Explosion in Zapolyarny

Table 7.5.3. Distances, travel times and velocities estimated for Event 1

Station Code	R (km)	D (deg)	VP (km/sec)	TT (sec)	VS (km/sec)	TT (sec)
APA	18.081	0.1631	5.752	3.1433	3.322	5.4433
APO	32.3	0.2901	6.102	5.2933	3.476	9.2933
LVZ	45.757	0.4116	5.987	7.6433	3.468	13.193
PLQ	147.186	1.3237	6.929	21.243	3.879	37.943
ARC	391.954	3.5255	7.044	55.643	4.043	96.943
FIN	781.881	7.036	7.490	104.39	4.250	183.99
SPI	1283.514	11.562	7.803	164.49	-	-
NRS	1308.326	11.787	7.896	165.69	4.472	292.54

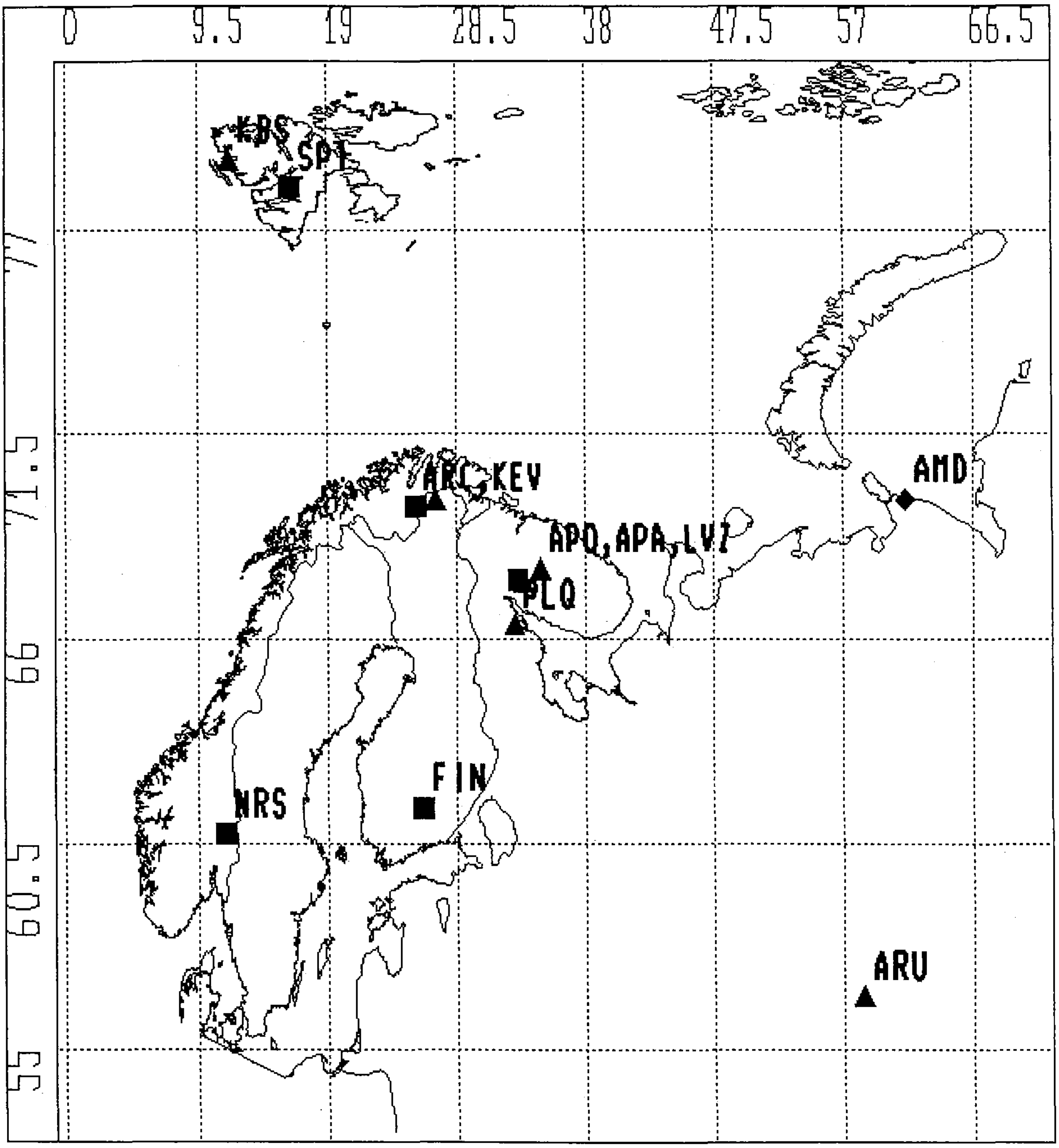


Fig. 7.5.1: Map showing the locations of seismic stations (triangles) and arrays (squares) used for this study. Station coordinates are listed in Table 7.5.1. The station ALE is not shown on the map.

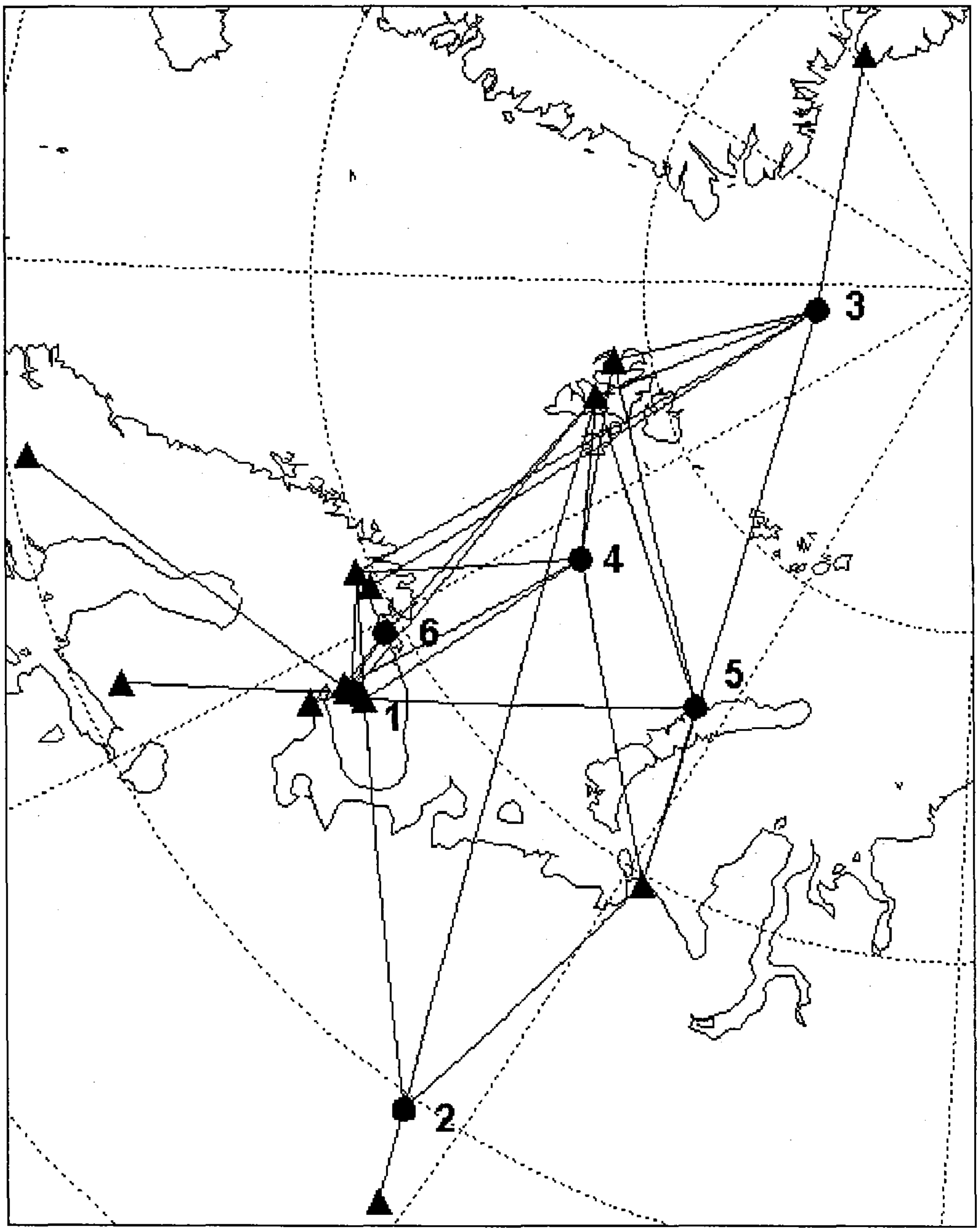
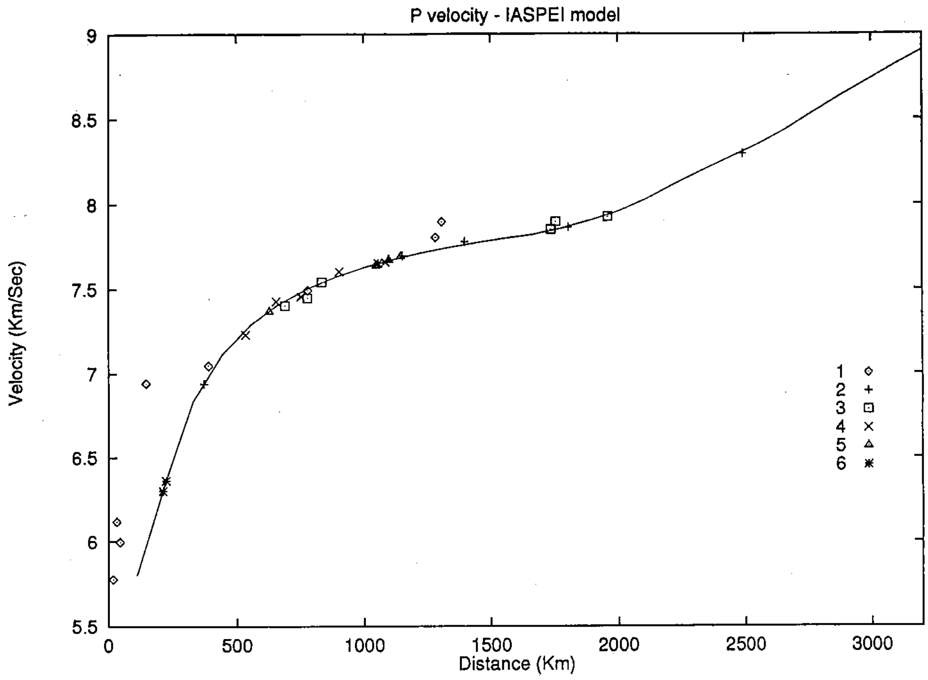


Figure 7.5.2: Station-event paths for the six seismic events used in this study. Only paths for which data has been available are shown.



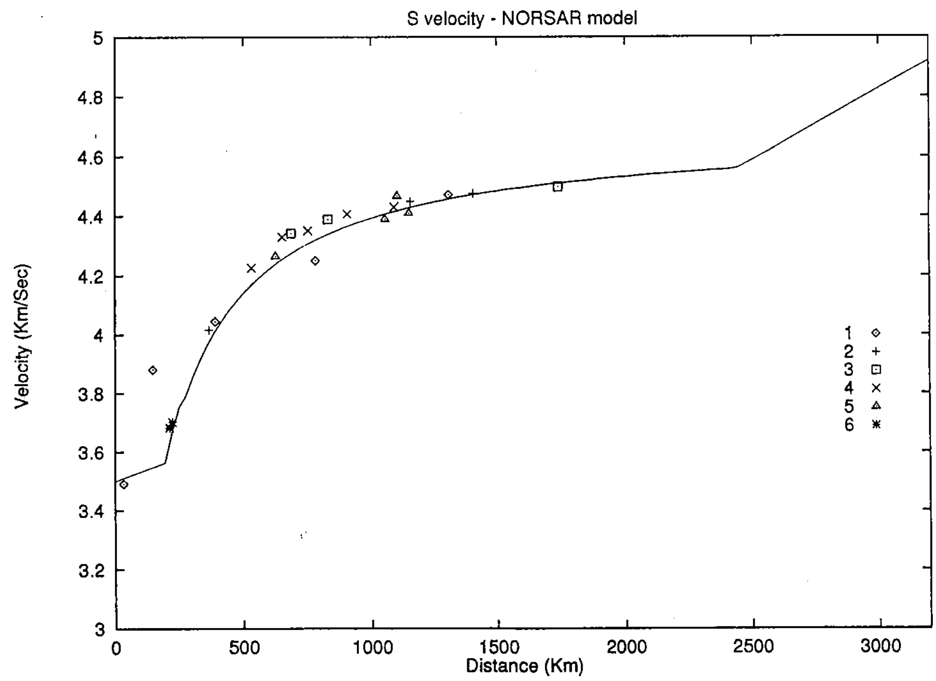
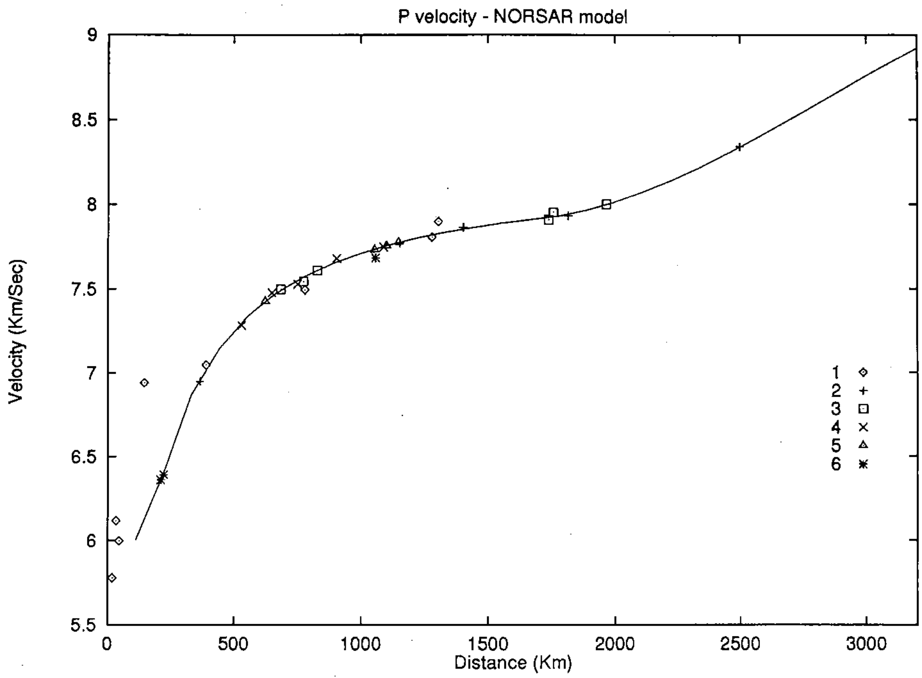


Fig. 7.5.3: Theoretical and observed P-velocities (top) and S-velocities (bottom) using the IASPEI travel-time model. The event locations used for this figure have been made on basis of the P-wave data using the IASPEI model, and consequently the P-wave data fits the model well. However, the predicted S-wave velocities are consistently lower than the observed data, indicating that the IASPEI model is not suitable for the region studied.



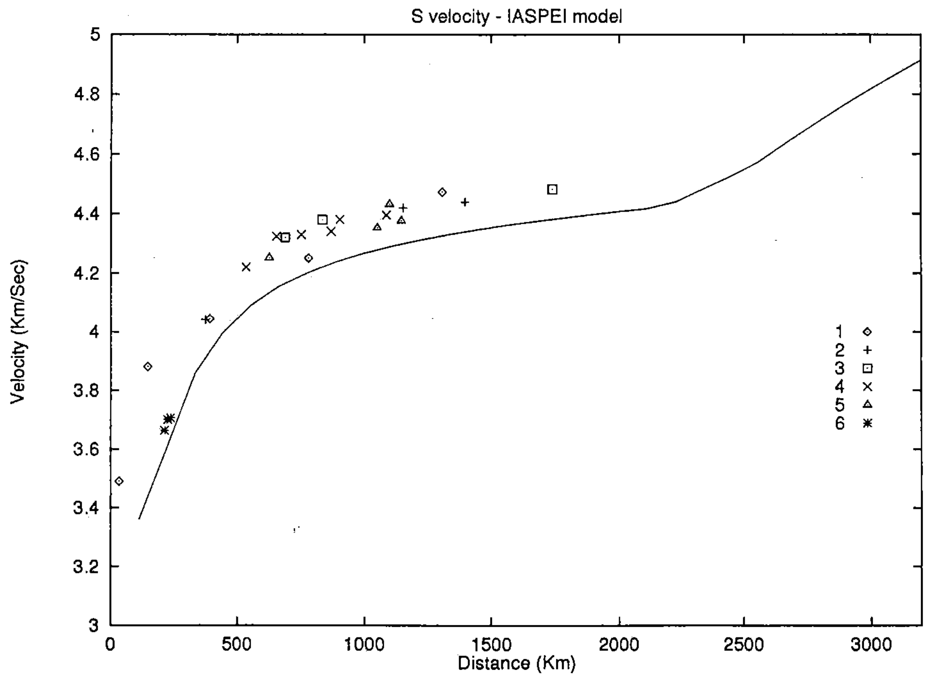


Fig. 7.5.4: Theoretical and observed P-velocities (top) and S-velocities (bottom) using the NORSAR travel-time model. The event locations used for this figure have been made on basis of the P-wave data using the NORSAR model, and consequently the P-wave data fits the model well. In addition, as opposed to Fig. 7.5.3, the predicted S-wave velocities are in quite good correspondence with the observed data, indicating that the NORSAR model is well suited for the region studied.

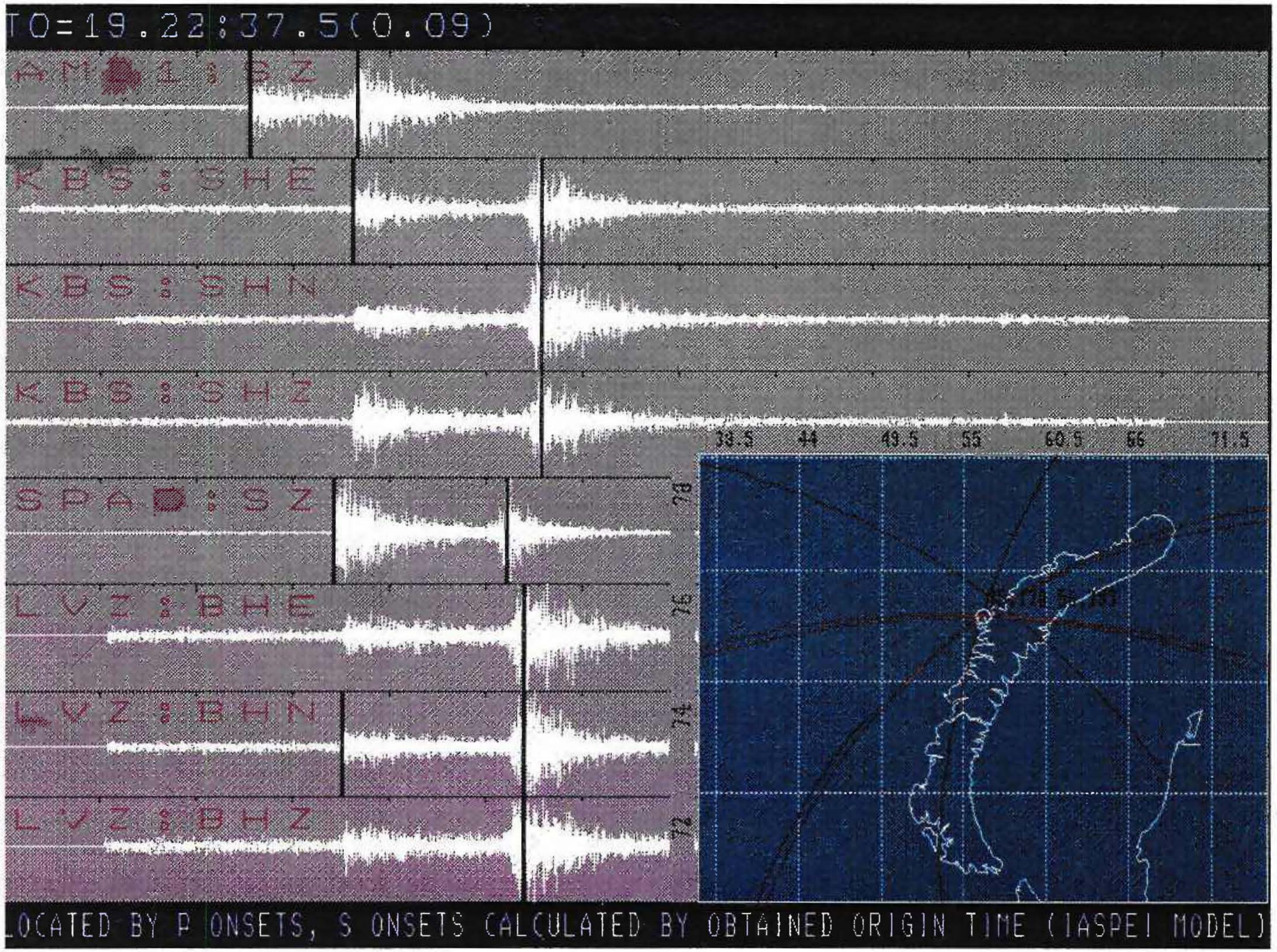


Fig. 7.5.5 Illustration of the predicted P and S phases for the IASPEI model for event 5 in the data base. The predicted time difference between P and S (vertical bars) clearly do not match the observed onsets.

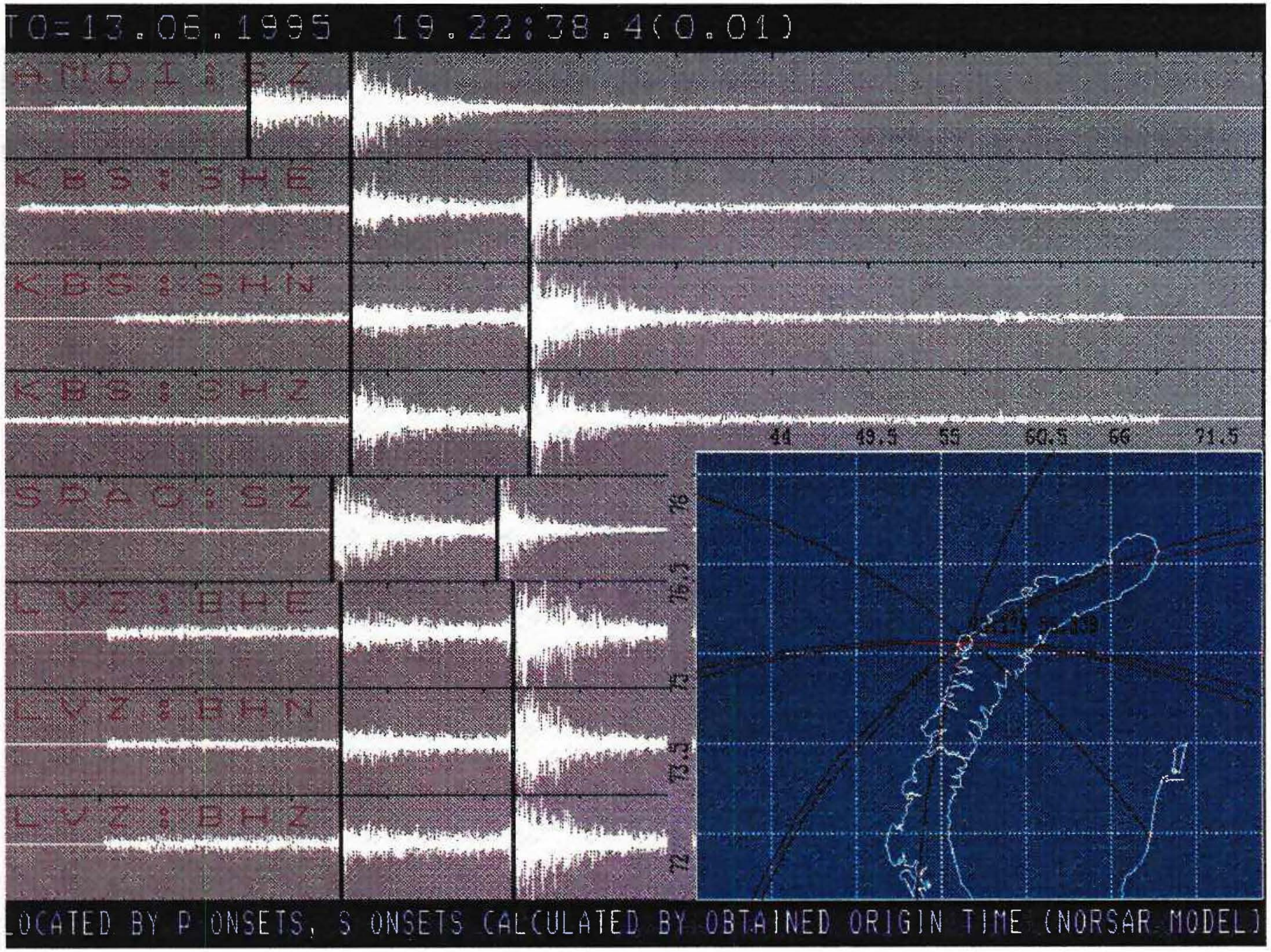


Fig. 7.5.6 Illustration of the predicted P and S phases for the NORSAR model for event 5 in the data base. In contrast to Fig. 7.5.5, the predicted time of arrival of P and S (vertical bars) match the observed onsets quite well.

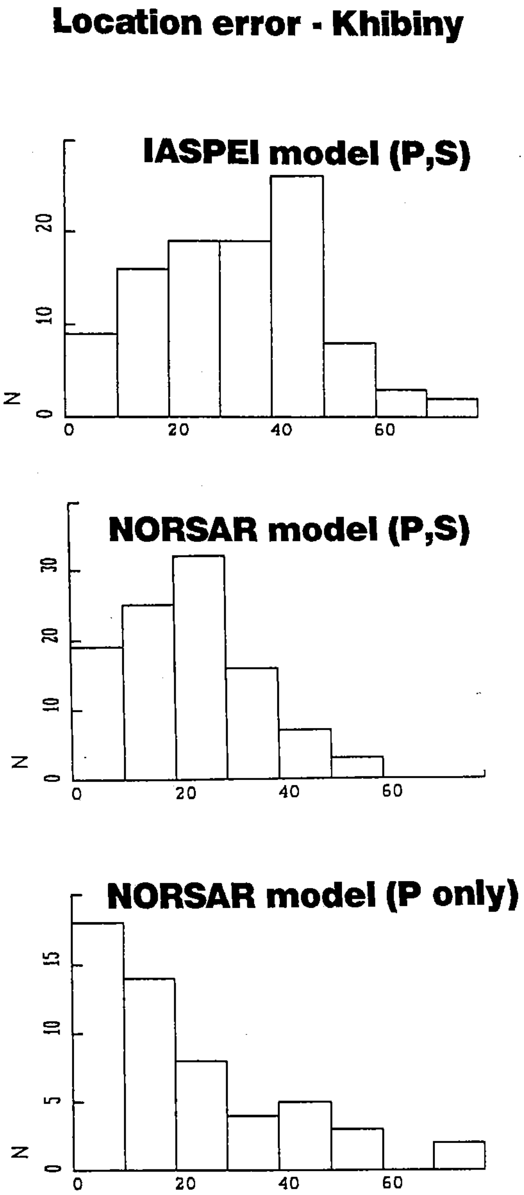


Fig. 7.5.7 Histograms showing the distribution of location errors for 52 Khibiny mining explosions: a) IDC locations (using P and S data with IASPEI model), b) Locations using IDC data (P and S) but with NORSAR model and c) Locations using P data only. Note that case c) shows less error for the majority of events, although there are some outliers.