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7.6 On the reliability of event location estimates from automatic and interactive processing

Introduction

The technique of automatic post-processing of seismic events (Kværna and Ringdal, 1994) has been shown to give a substantial improvement in location accuracy when applied to seismic events in the Khibiny Massif, Kola Peninsula. As shown in that paper (see also Ringdal et al, 1993), the improvement is significant not only relative to automatic processing by the Intelligent Monitoring System (IMS), but also compared to interactive analyst-reviewed solutions.

The improvements are particularly noteworthy since the IMS already shows an excellent location capability in this area (median location error 10.6 km for the automatic solutions and 3.3 km for the analyst-reviewed solutions). By the automatic post-processing method, the median error is reduced to 1.9 km, even when no calibration is carried out. The improvements are even larger when considering the 90% quantile in the location errors; the corresponding numbers being 48.4 km, 9.7 km and 3.6 km for the three cases.

In order to take full advantage of the improved accuracy, it is essential to provide realistic confidence ellipses for the location estimates. In this contribution we discuss the confidence ellipses associated with the various processing methods, and make some observations regarding their reliability as an uncertainty measure. The data base established in the studies described above has been used.

The Khibiny Massif events

Six apatite mines are located within an area of about 10 km^2 in the Khibiny Massif on the Kola Peninsula of Russia (see Fig. 7.6.1). A detailed description of these mines and the mining activity is found in Mykkeltveit (1992). Although we have no explicit information on the exact sizes of these mines, interpretation of various maps suggests that the typical size is about 1 km^2. The Kola Regional Seismological Centre has since the beginning of 1991 provided NORSAR with information on mining blasts in the six Khibiny Massif mines. Detailed information on the events used in this study is given in Kværna (1993).

Data analysis

As reported by Kværna (1993), available data for this study have comprised 4 arrays (NORESS, ARCESS, FINESS, Apatity) as well as the 3-comp Apatity station APZ9. We have considered the location results using four different analysis methods:

1. Automatic IMS analysis, based on available array data (4 arrays)
2. Interactive analyst results using the Analyst Review Station (ARS) (4 arrays + APZ9)
3. Automatic post-processing without calibration (2 arrays: ARCESS and Apatity)

4. Automatic post-processing with calibration (2 arrays + APZ9)

For each event in the data base, we computed the associated 90% confidence ellipse for each of the four methods. For methods 1 and 2, we used the error estimates of time and azimuth provided by the IMS processing system for calculating the error ellipses. As explained by Bache et al (1990), these error estimates take into account both a priori model uncertainties and uncertainties resulting from actual signal-to-noise ratios. For methods 3 and 4, we used error estimates of time and azimuth computed by Kværna (1993). These latter estimates were set to the same value regardless of actual signal-to-noise ratio. An example comparing the uncertainties used for each method is shown for one typical event in Table 7.6.1, using phases from the ARCESS and Apatity arrays.

We then plotted the solutions and the confidence ellipses for all events, as shown in Figs. 7.6.2-7.6.4. For clarity, different colors have been used for each of the six mines, and each figure shows the solutions in two different scales.

Our general observations, also discussed in Ringdal et al (1993), are:

- The interactive IMS solutions (Fig. 7.6.3) are significantly more accurate and consistent than the automatic IMS solutions (Fig. 7.6.2).
- The automatic post-processing solutions are still better than the interactive IMS solutions, even without calibration (Fig. 7.6.4). This is in spite of the fact that post-processing makes use of only 2 arrays.
- With calibration, the results are even more accurate. Fig. 7.6.5 shows the "optimum" results achieved by post-processing with calibrated data, where also the Apatity 3-comp station has been used.

Information on the percentage of events for which the 90% confidence ellipse includes the actual location is given in Table 7.6.2. The following observations are made:

IMS automatic processing:

Only 54% of the error ellipses cover the actual epicenter. This means that these ellipses do not represent the accuracy of the solutions properly.

IMS interactive processing:

93.9% of the error ellipses cover the actual epicenter. Thus the error ellipses are quite representative of the actual accuracy in this case.

Automatic post-processing (uncalibrated):

98.0% of the error ellipses cover the actual epicenter. Thus, the error ellipses are probably too conservative in this case.

Automatic post-processing (calibrated):

90.0% of the error ellipses cover the actual epicenter. Thus the error ellipses represent very well the actual uncertainty for this method.

Conclusions

For the automatic IMS, the error ellipses are currently too small. The main reason is probably that they do not take into account effects of occasional erroneous phase identification by the automatic system. It is noted here that the formal calculation of error ellipses assumes that the phases are correctly identified.

For the interactive IMS solution, the error ellipses are quite representative. This indicates that the a priori uncertainties in the phases used by the location program have been well estimated. Consequently, the interactive IMS solutions have an accuracy that is well represented by their error ellipses, at least for the region processed here.

For the post-processing method using uncalibrated data, it seems necessary to reduce the a priori uncertainties, thus producing smaller error ellipses. With calibrated data, the ellipses are representative for this particular data set. However, it is important that other regions be studied as well before making any firm conclusions.

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Phase	Method 1 (IMS)		Method 2 (ARS)		Method 3 & 4 (Post-proc.)	
	Time	Az	Time	Az	Time	Az
Apatity Pg	1.0	5.4	1.0	5.4	0.1	-
Apatity Lg	3.0	6.5	3.0	-	0.25	-
Apatity Rg	-	-	3.1	3.2	-	4.0
ARCESS Pn	1.0	6.0	1.0	6.0	0.1	4.0
ARCESS Pg	2.1	5.5	2.1	5.5	-	-
ARCESS Sn	2.1	6.6	2.1	6.6	-	-
ARCESS Lg	3.0	5.5	3.0	5.5	-	-

Table 7.6.1. Example of uncertainties used for calculating error ellipses. Note that the estimates for Methods 1 and 2 are identical. whenever the same phase has been used.

Method	Mine						Total	%
	1	2	3	4	5	6		
IMS automatic	9/11	0/2	7/11	7/12	3/10	1/4	27/50	54.0
IMS interactive	10/11	2/2	10/11	12/12	8/9	4/4	46/49	93.9
Post--processing (uncalibrated)	12/12	2/2	11/11	12/12	9/10	4/4	50/51	98.0
Post-processing (calibrated)	10/11	2/2	11/11	12/12	7/10	3/4	45/50	90.0

Table 7.6.2. Number and percentage of events for which the 90% location confidence ellipse includes the actual epicenter. Numbers are given for each of the 6 mines individually and combined.

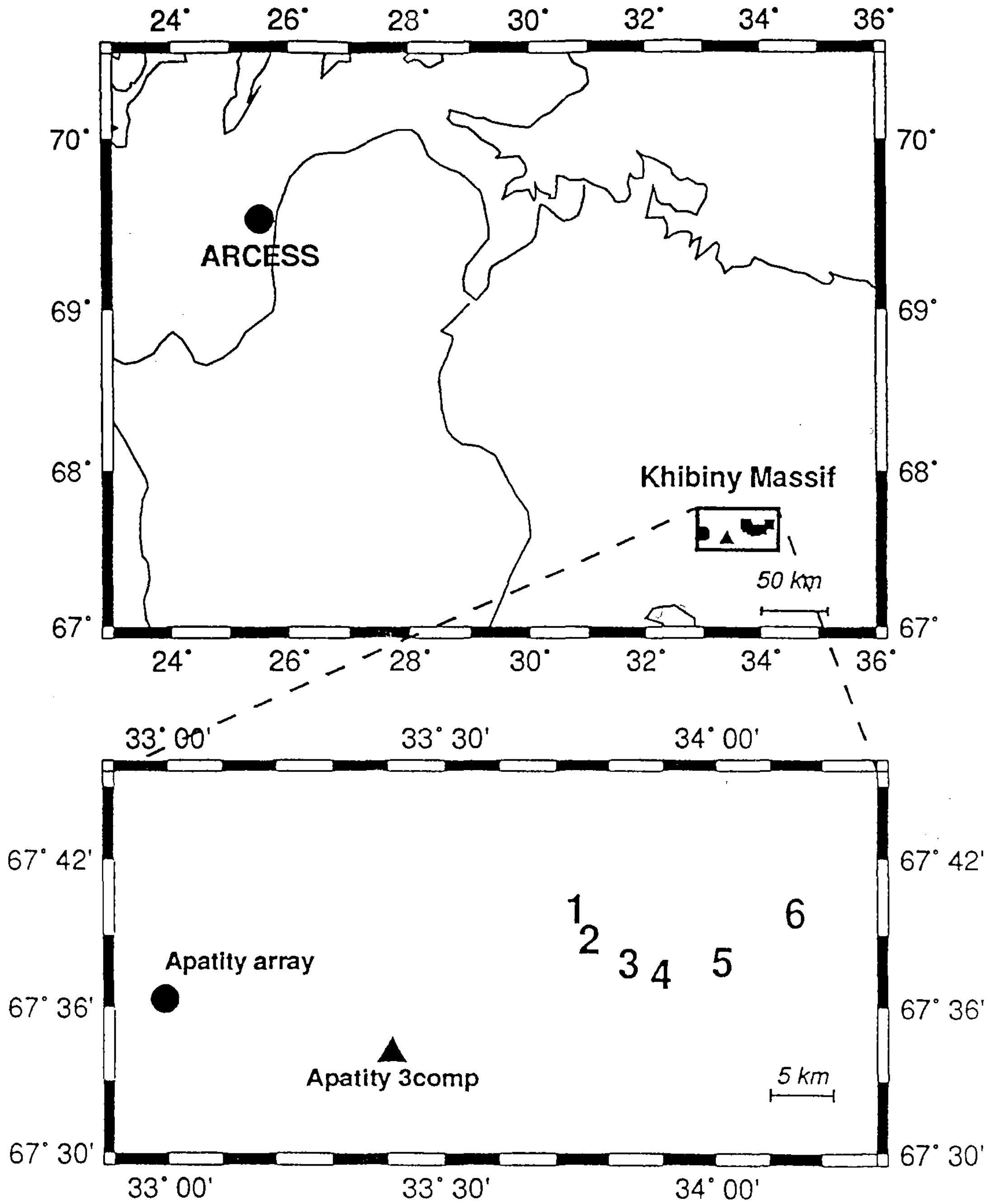

Fig. 7.6.1. In the *upper part*, a large reference area is shown. The location of the ARCESS array is given by a filled circle, and the location of the Khibiny Massif region is shown. The *lower part* shows a detailed picture of the Khibiny Massif region. The locations of the six mining sites are given by large numbers 1-6. The Apatity array (APA0) is shown as a filled circle, and the three-component station (APZ9) in the town of Apatity is shown as a large triangle.

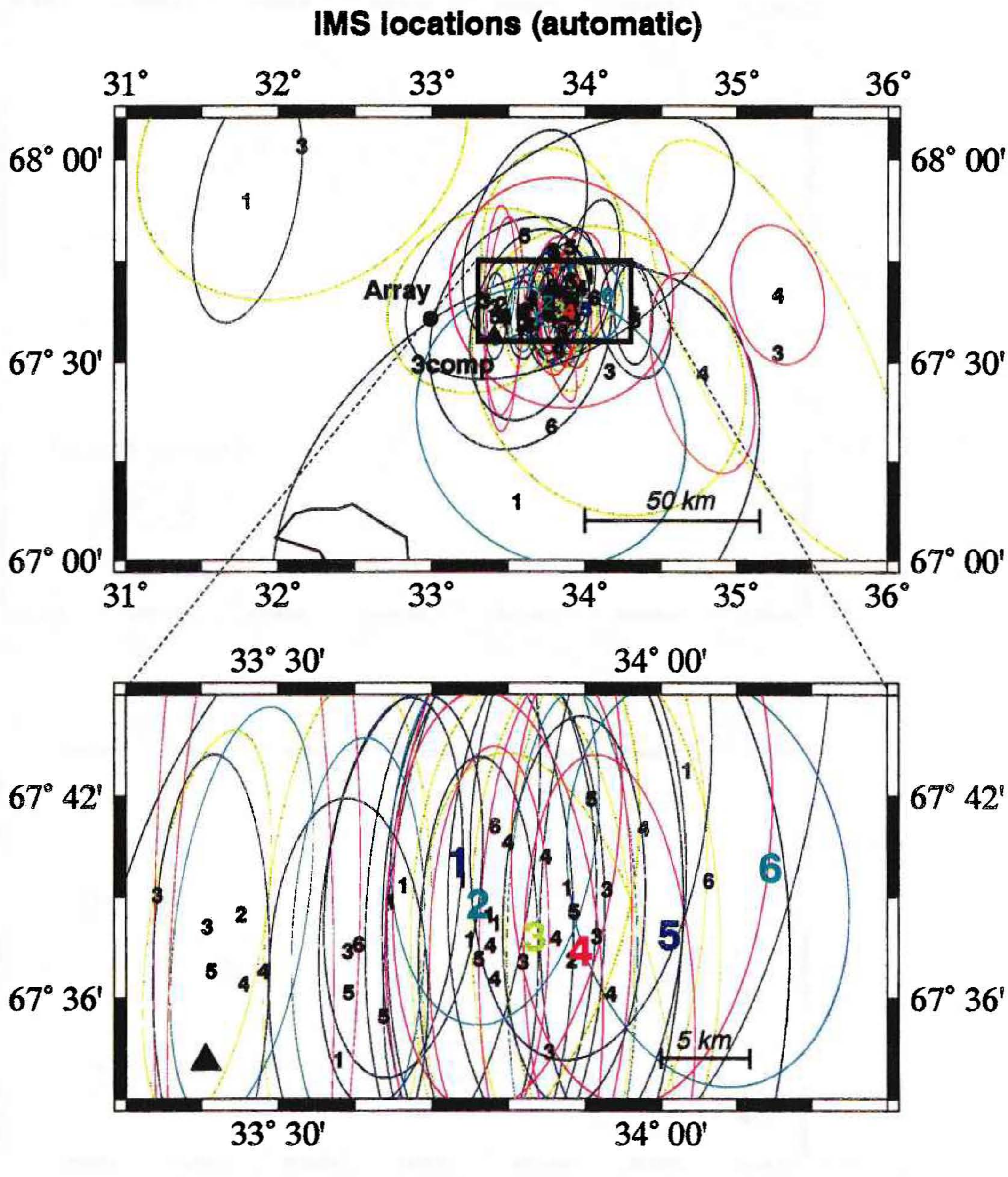

Fig. 7.6.2. Location error ellipses for automatic IMS processed events. The large numbers are actual mining sites, and the small numbers are corresponding location estimates.

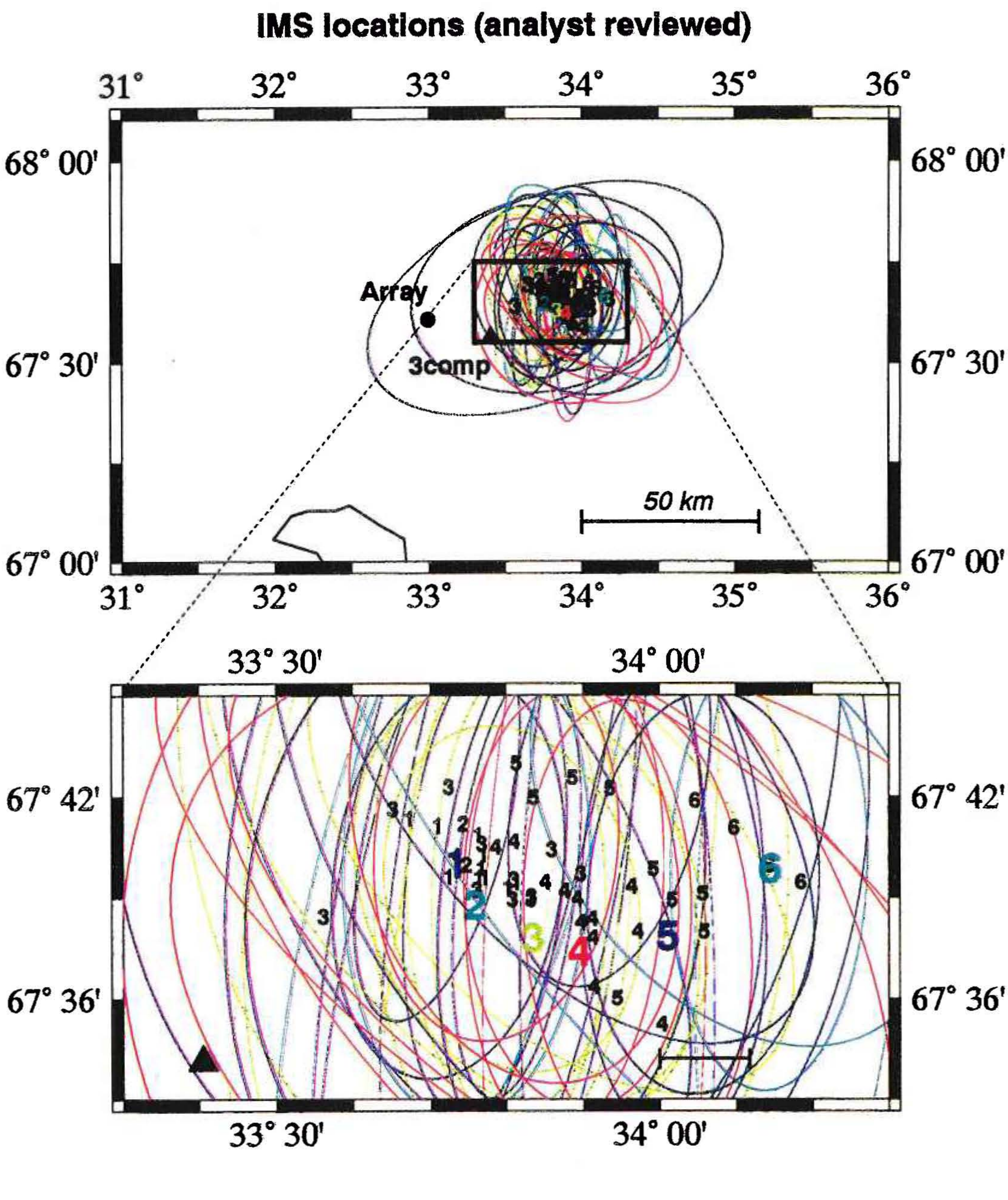

Fig. 7.6.3. Same as Fig. 7.6.2, but corresponding to the IMS analyst-reviewed location estimates.

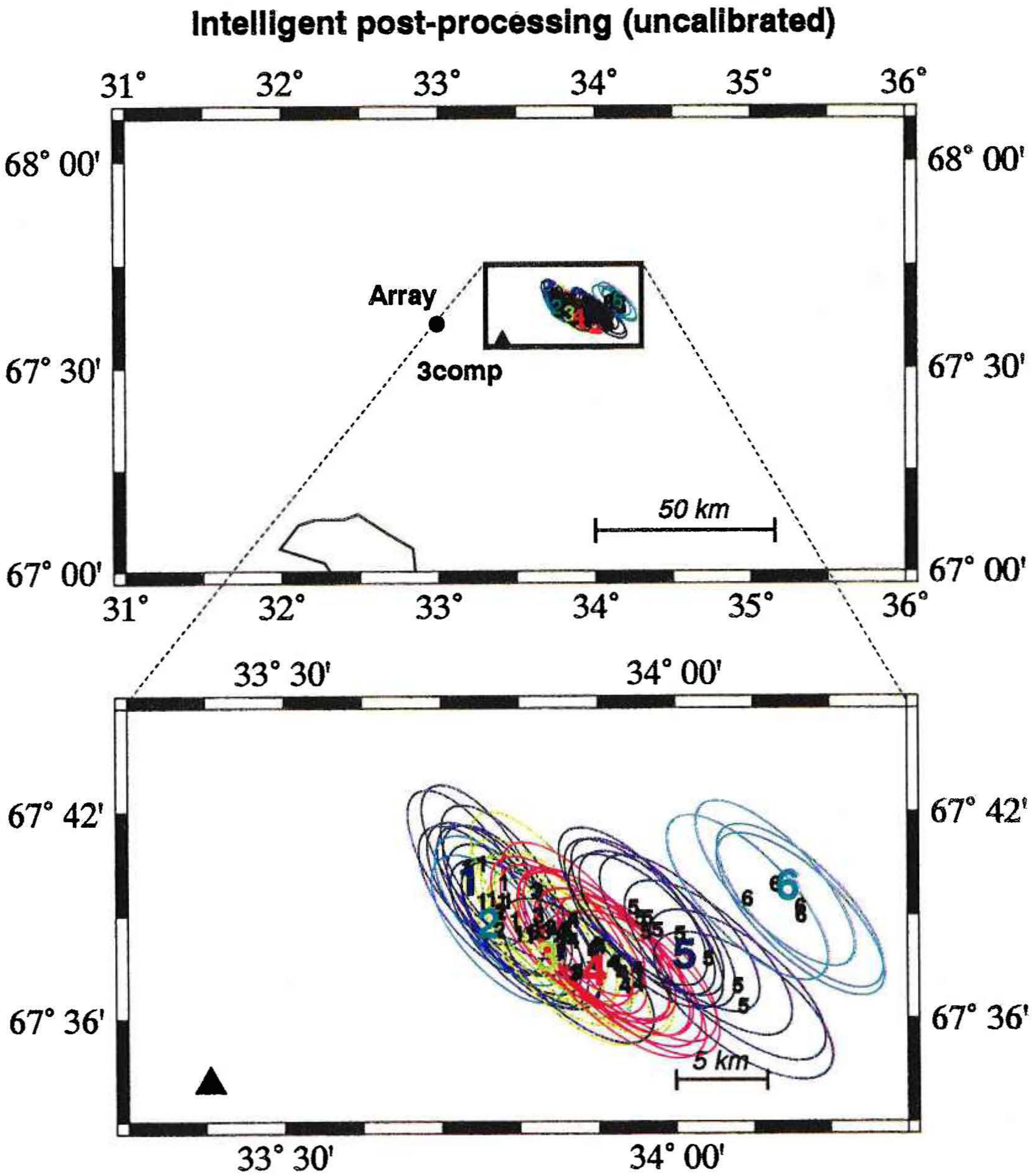

Fig. 7.6.4. Same as Fig. 7.6.2, but corresponding to the automatic post-processing location estimates, using ARCESS and Apatity array data with no calibration.

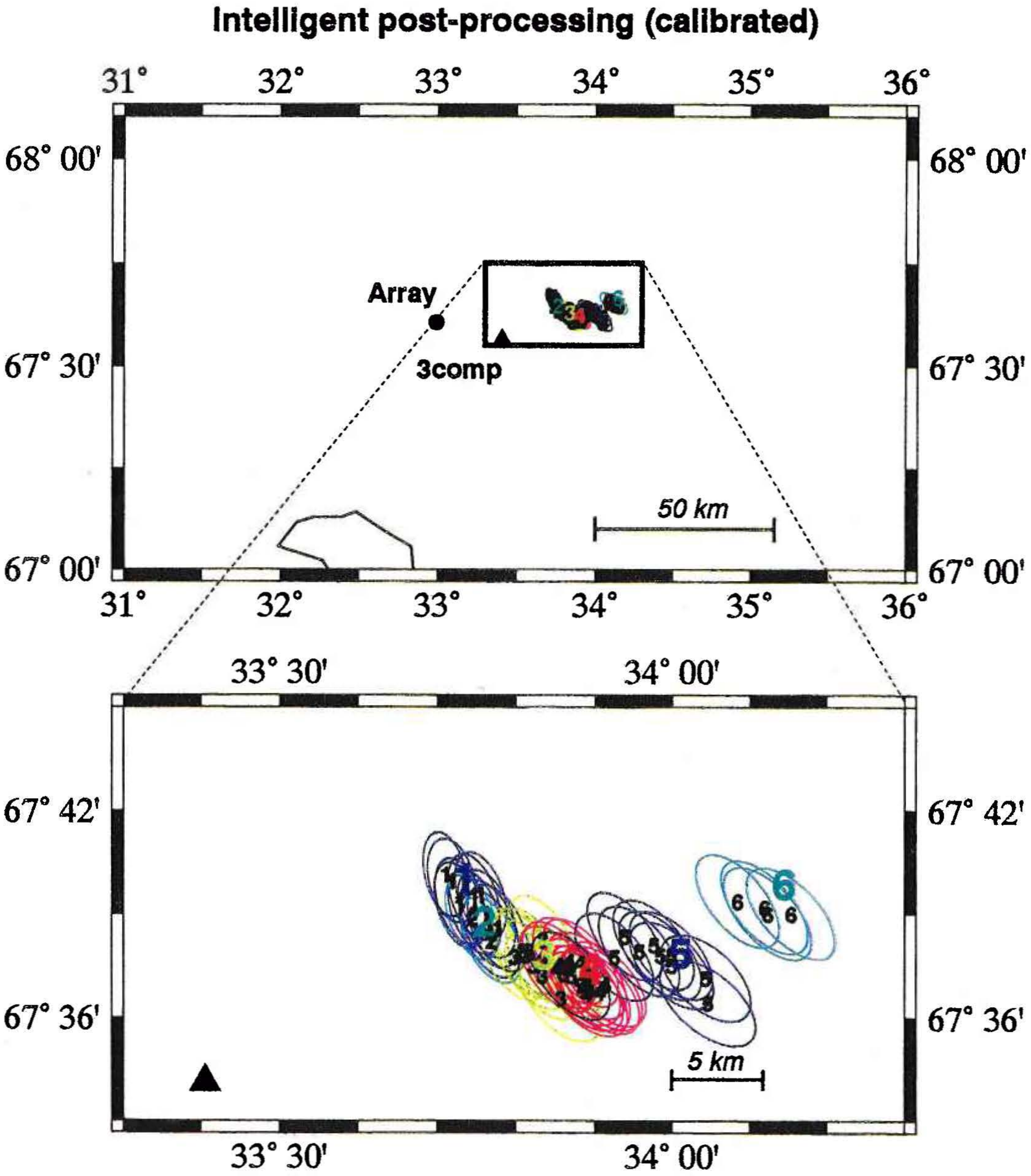

Fig. 7.6.5. Same as Fig. 7.6.2, but corresponding to the automatic post-processing location estimates, using calibrated data from ARCESS, the Apatity array and the Apatity 3-comp station.