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7 Summary of Technical Reports / Papers Published

7.1 Global seismic threshold monitoring and automated network processing

Paper presented at the ARPA CTBT Monitoring Technologies Conference 1995

Abstract

The overall objective of the research conducted at NORSAR is to develop, test and demonstrate advanced automated processing techniques for use in a global seismic CTBT monitoring system, and to implement and integrate these techniques into the processing at the International Data Center. A global system for continuous seismic threshold monitoring has been developed and implemented at the IDC. Other advances include improved automatic onset time estimation of signal arrivals, special post-processing procedures for improving automatic event location accuracies and on-line regional generalized beamforming for reliable phase association of detected seismic events.

Background

Over the past several years, major advances have been made in automated processing of seismic data for regional and global monitoring. These range from automated array and 3-component station detection processing and parameter extraction using techniques such as frequency-wavenumber analysis to automated, expert-system processing at both the single-station and network level. Advances have also been made in regional and global phase association techniques. Nevertheless, the current IDC processing requires a high degree of analyst interaction before the final bulletin is produced. While the current interactive analysis tools at the IDC are both sophisticated and effective, the need for further automation of the analyst functions is clearly present. Such added automation would also contribute to enabling the analysts to focus on events of special interest, rather than spending the majority of their time on routine events.

Global threshold monitoring

Our main emphasis has been on developing and implementing a system for global continuous threshold monitoring at the IDC. Continuous seismic threshold monitoring (CSTM) is a technique that has been developed over the past few years to monitor a geographical area continuously in time. Data from a network of arrays and single stations are combined and “steered” toward a specific area to provide an on-going assessment of the upper magnitude of seismic events that might have occurred in that area.

The main purpose of the technique is to highlight instances when a given threshold magnitude is exceeded, thereby helping the analyst to focus on those events truly of interest in a monitoring situation. The analyst can then apply traditional tools in detecting, locating and identifying the source of the disturbance. Thus, the CSTM technique is designed to supplement, not to supplant, traditional techniques.

Approaches to CSTM include:

- Site-specific monitoring: A seismic network is focused on a small area, such as a known test site. This narrow focusing enables a high degree of optimization, using site-station specific calibration parameters and sharply focused array beams.
- Regional monitoring: Using a dense geographical grid, and applying site-specific monitoring to each grid point, threshold contours for an extended region are computed through interpolation. In contrast to the site-specific approach, it is usually necessary to apply generic attenuation relations, and the monitoring capability will therefore not be quite as optimized.
- Global monitoring: This is similar to regional monitoring, but the global grid system is much less dense, and the threshold parameters are most often determined from teleseismic (rather than regional) phases. This approach is expected to be particularly useful at the IDC in a monitoring system.

The CSTM approach has an advantage over standard capability maps in the following respects:

- The threshold levels represent the actual noise conditions at any point in time, and do not depend upon an assumed noise distribution.
- After a large earthquake, the ensuing increase in global threshold levels is accurately represented.

These features are illustrated in Figs. 7.1.1-7.1.4.

Generalized beamforming

Another area of activity has been the development and fine-tuning of regional generalized beamforming (GBF) for the Fennoscandian area. Based upon statistics accumulated over the past several years, it is found that this technique is very effective in providing reliable phase association and initial location estimates, for use in subsequent processing by the Intelligent Monitoring System (IMS). The results from the GBF process are now available on-line on the Internet (finger quake@ugle.norsar.no).

The following specific results have been obtained:

- The Alpha station network in Fennoscandia (NORESS, ARCESS, FINESS, Hagfors) detects thousands of regional events annually.
- More than 95 per cent of these events are man-made.
- Most events are confined to a small number of mining regions.
- Typical location accuracy (after analyst review) is about 10 km.
- Very few man-made events (only about 10 per year) exceed $m_b = 3$.

Fig. 7.1.5 illustrates the principles of regionalized GBF and the results obtained.

Automatic post-processing

An experiment has been conducted for one of the most active mining regions, located on the Kola Peninsula. The small array in Apatity, Kola, located less than 50 km from this area, has been used as a Beta station in an automatic processing scheme. We have also used a 3-component station nearby. Results are as follows:

- By autoregressive techniques, and applying fixed filter bands and processing parameters, an onset time accuracy comparable to analyst picks has been achieved.
- Automatic relocation of the events using the Beta stations has resulted in a significantly improved accuracy (about 2 km) in epicenter location.
- These results have been confirmed by independent "ground truth" locations provided by the Kola Science Centre.

The results of this experiment are illustrated in Fig. 7.1.6.

An important perspective is that suitably placed Beta stations near mining areas could be used to obtain improved automatic location accuracy of mining events, and could reduce analyst workload considerably. While our work has made use of a small Beta-array, a 3-component station might be expected to provide nearly as good results when processed in this manner.

Another important result of years of monitoring seismic events in Fennoscandia is the virtual absence of mining explosions exceeding $m_b = 3.0$. Also, very few of the events exceed $m_b = 2.5$. If such mining practice is typical, it might be important in reducing the number of events of real monitoring concern.

We are currently applying the autoregressive onset estimation technique to seismic phases on a more general basis, and investigating the quality of the results as a function of filter setting and signal-to-noise ratio. Reliable quality indicators are the key to a successful application of the post-processing technique in a wider context. One important consideration is to obtain the appropriate weighting of the observations in the location scheme, such that reliably determined arrival times will be given far higher weights than less reliable ones.

Conclusions and recommendations

The Continuous Seismic Threshold Monitoring has been demonstrated to provide a simple and very effective tool in day-to-day monitoring of a site of particular interest, and thereby offers a valuable supplement to traditional techniques in nuclear test ban monitoring. The initial version of this system has now been implemented at the IDC.

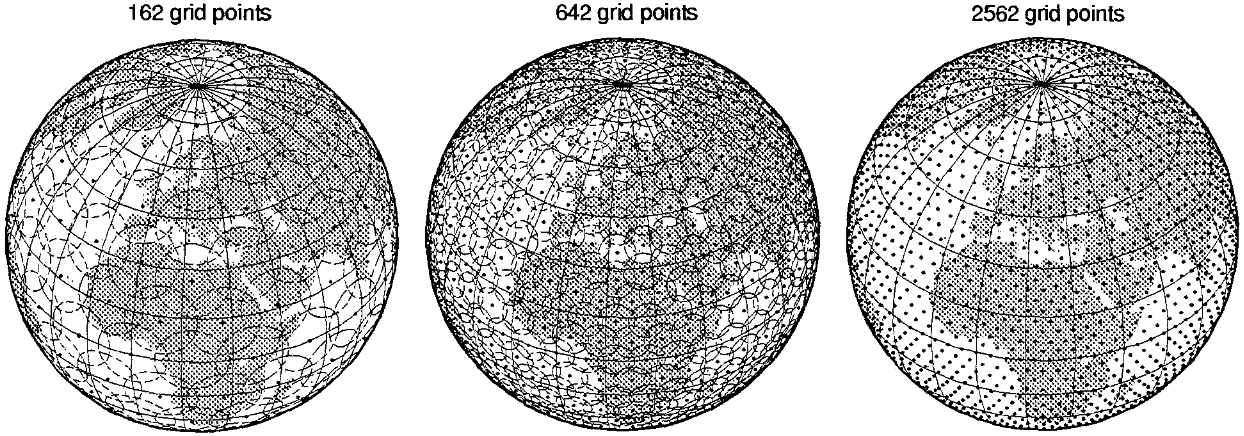
The future work will concentrate on refining CSTM analysis, both site-specific and regional, using map displays. The system will be further integrated with the IDC parameter-based processing, and the peaks on the threshold traces will be analyzed with an automatic event explanation facility based on the IDC bulletin. In cases when the CSTM results suggest that further off-line analysis should be invoked, the IDC Analyst Review Station will be used. In support of the IDC subscription service, we will explore various means to provide data to requesting parties, including AutoDRM and use of the WWW map facility.

In our view, the deployment of advanced small-aperture arrays and the associated development and implementation of automated and increasingly powerful data processing techniques represent major advances in seismic monitoring in recent years. We have demonstrated the potential of improved event definitions at the IDC by refining the phase arrival times and taking regional calibration data into account. Additional research along these lines and subsequent implementation into the IDC of appropriate procedures is needed in order to fully exploit the potential of the array network data, and will be an important focus of our future research.

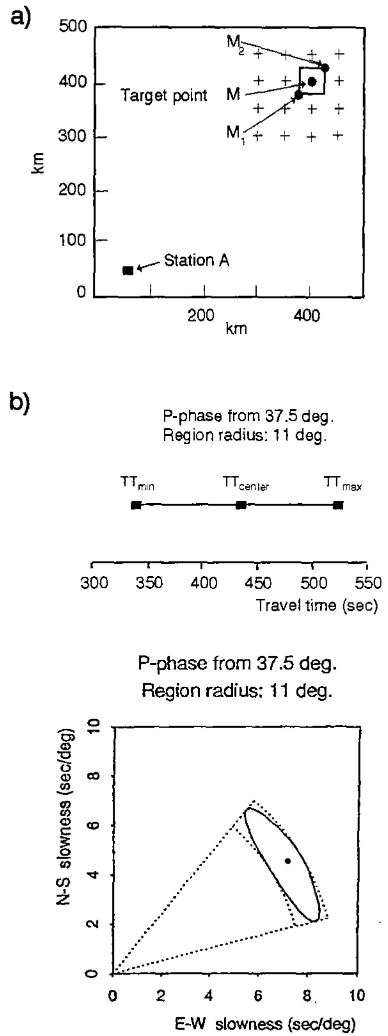
F. Ringdal
T. Kværna
S. Mykkeltveit

Global Threshold Monitoring — Method Development

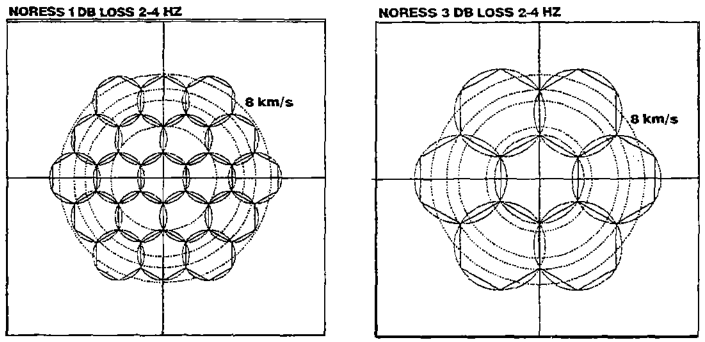
Developing a global grid system for deploying the generalized beams



Azimuth and travel time tolerances



Compensating beam loss



Relating STA to m_b

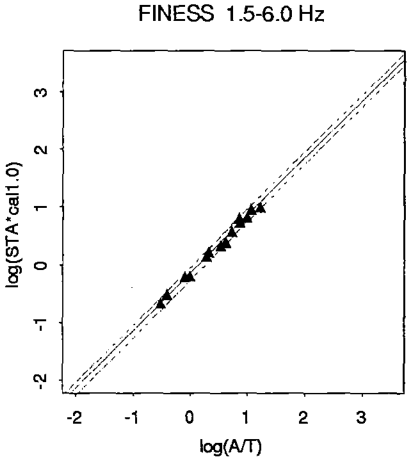


Fig. 7.1.1.

Global Threshold Monitoring — IDC Implementation

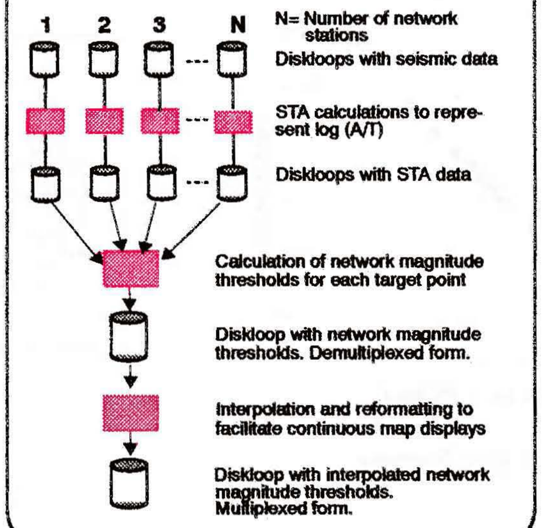
Initial IDC implementation

- Continuous Threshold Monitoring map
- 642 or 2562 grid points
- 10 seconds update rate
- 7-day diskloop of STA values
- Regional map displays available
- Site-specific traces extracted on request

Comments:

- Site-specific traces will be interpolated from the global map
- "Optimum" site-specific traces may be available in the future

Processing Flow



1 2 3 --- N

N= Number of network stations

Diskloops with seismic data

STA calculations to represent log (A/T)

Diskloops with STA data

Calculation of network magnitude thresholds for each target point

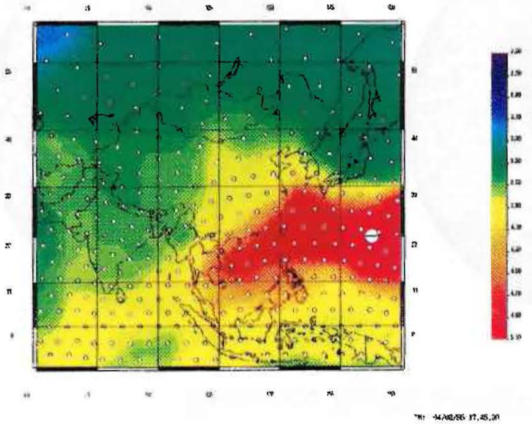
Diskloop with network magnitude thresholds. Demultiplexed form.

Interpolation and reformatting to facilitate continuous map displays

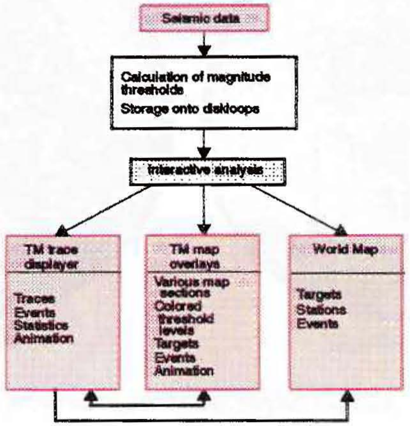
Diskloop with interpolated network magnitude thresholds. Multiplexed form.

CSTM services provided by the IDC

- World threshold map (e.g., postscript file) at a given point in time
- Site-specific trace (taken from world map) for specified target and time period
- Either data points or trace plot provided
- Specification of IDC events associated with peaks on the trace plot
- Use of CenterView, Data Request Manager, or other mechanisms



Interactive Analysis



Seismic data

Calculation of magnitude thresholds

Storage onto diskloops

Interactive analysis

TM trace displayer

Traces
Events
Statistics
Animation

TM map overlays

Various map sections
Colored threshold levels
Targets
Events
Animation

World Map

Targets
Stations
Events

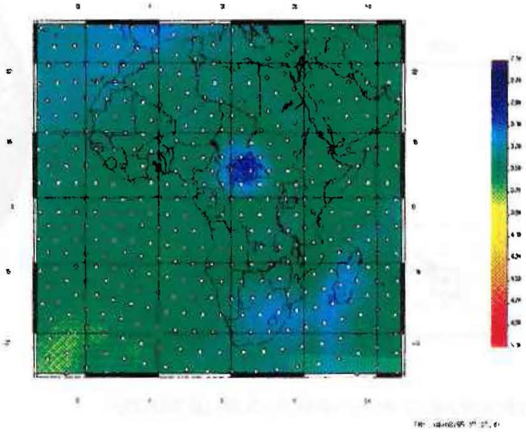


Fig. 7.1.2.

Global Threshold Monitoring — Monitoring Examples

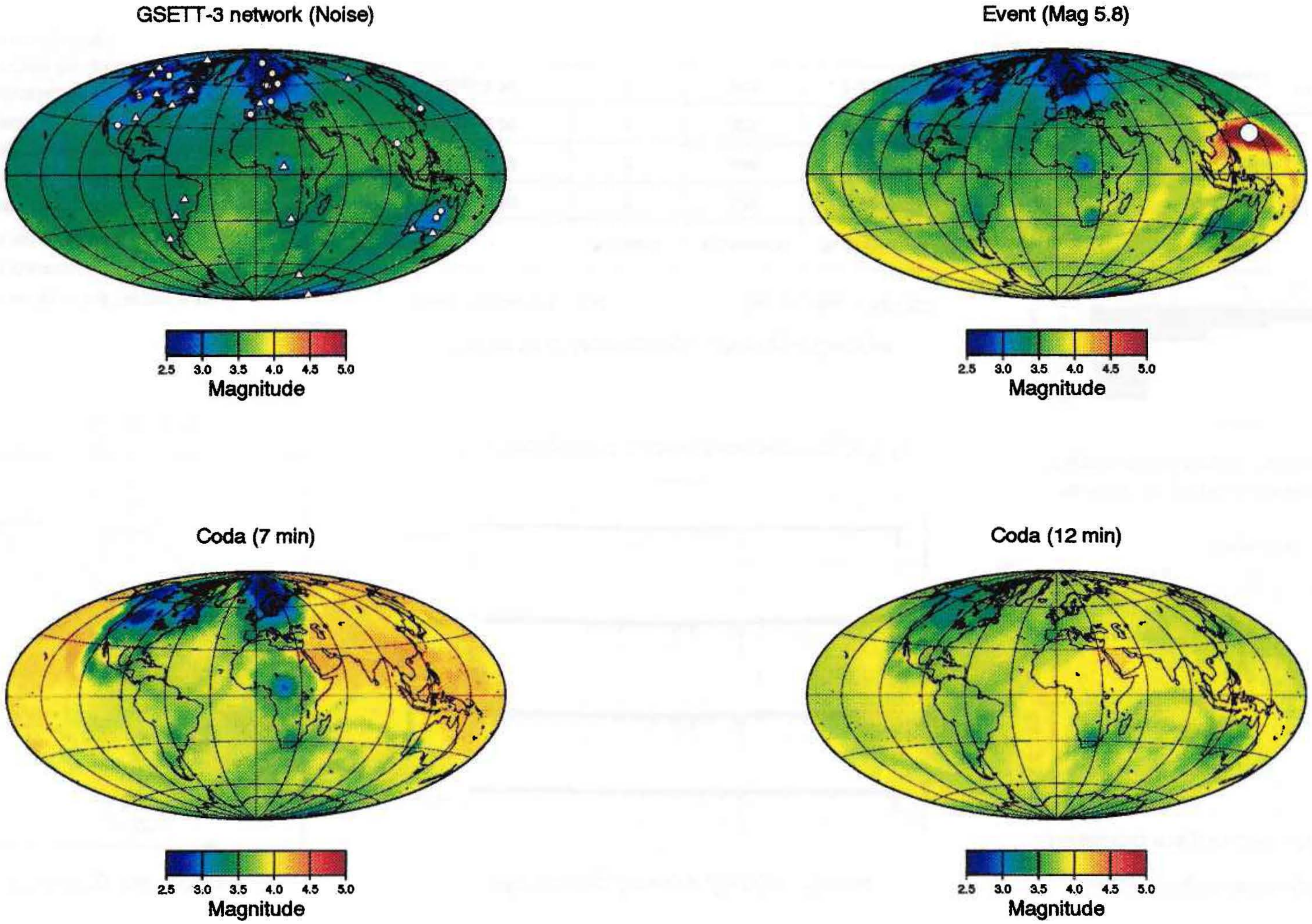
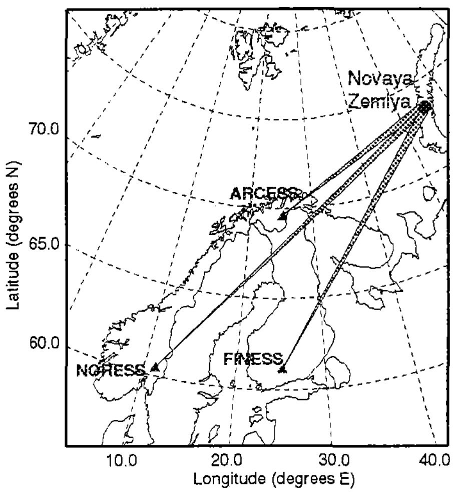


Fig. 7.1.3.

Site-Specific Threshold Monitoring

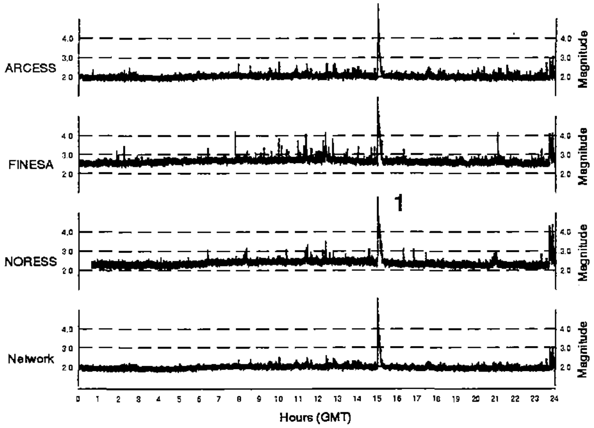
Focusing the network



Principles:

- Focus each array on a target site
    - Optimum beams
    - Optimum filter bands
- Apply probabilistic model to obtain estimate of upper magnitude level (90% confidence)
- Examine and explain peaks on the network threshold trace
- Special applications possible (e.g., monitoring high frequencies for evidence of possible decoupled explosions)

Monitoring Novaya Zemlya, Russia



(1) Underground nuclear explosion ($m_b = 5.7$)

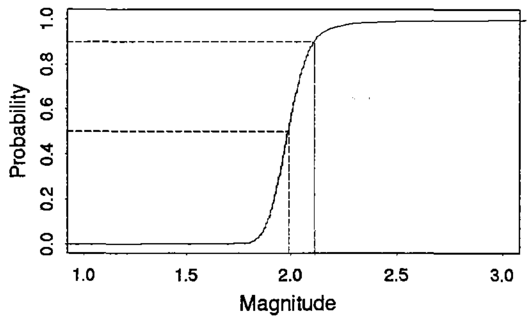
Threshold Monitoring — Novaya Zemlya

Date: October 24, 1990 Day_of_Year: 1990-297

	# Peaks	# Seconds	% of time
Mag>2.50	3	670	0.78
Mag>2.75	2	440	0.53
Mag>3.00	1	325	0.40
Mag>3.50	1	200	0.27

Computing threshold statistics

Threshold magnitudes - Novaya Zemlya



Number of peaks exceeding given magnitude threshold (30 days statistics)

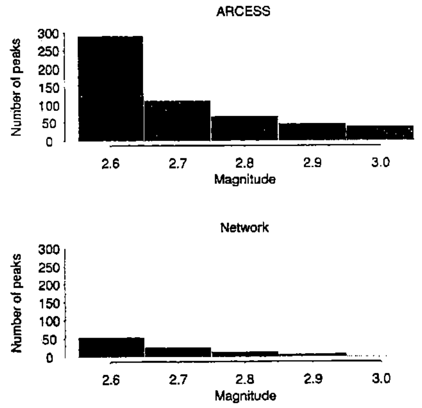


Fig. 7.1.4.

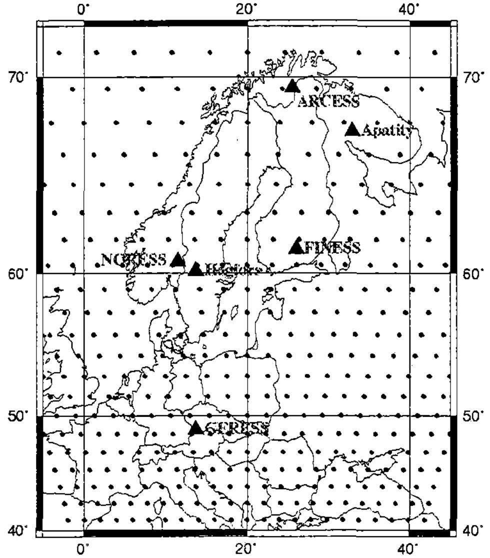
1. Regular operation at NORSAR since 1989
2. Covers Fennoscandia/N. Europe
3. Coarse initial beam grid, supplemented by beampacking
4. Available on-line by finger quake@ugle.norsar.no
5. Location accuracy typically 30 km
6. Automatic post-processing for accurate location under implementation

Internet access:

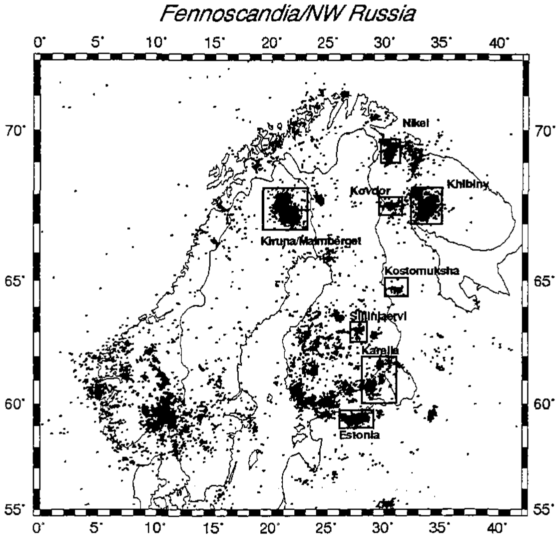
NORSAR"s Automatic Array Epicenter Solutions

```
        Origin Time            Lat    Lon   Mag  Timres  Azres  N:Tot  Pha  Sta  Sta    Dist  Snr
1995   4  25  5:07:04   66.95  12.09  1.5    0.16   2.95      4    2    1  ARC    624    4
1995   4  25  6:31:23   59.99  22.59  1.2    0.53   1.90      2    2    1  FIN    249   15
1995   4  25  7:31:58   60.09  22.55  1.7    0.77   2.40      4    4    2  FIN    244   13
1995   4  25  7:33:20   63.19  23.76  1.2    0.66   1.45      2    2    1  FIN    229    7
1995   4  25  7:38:35   74.15  35.73  1.7    0.20  11.10      2    2    1  ARC    624    6
1995   4  25  7:59:20   70.85  17.71  1.1    0.33   7.65      3    2    1  ARC    329   11
1995   4  25  8:05:28   60.09  22.55  1.3    0.38   6.70      2    2    1  FIN    244   14
1995   4  25  8:15:45   59.59  10.23  1.2    0.42   3.30      7    4    2  NRS    147   63
1995   4  25  8:39:35   67.85  36.87  1.1    2.73   3.36      4    2    1  APA    166   27
1995   4  25  8:49:05   58.55  27.26  2.0    2.14   3.26      5    3    2  FIN    329    7
1995   4  25  9:05:02   61.99  23.01  1.2    0.48   3.82      2    2    1  FIN    173   40
1995   4  25  9:13:30   68.15  33.40  1.9    2.75   9.40     11    6    2  APA     63  380
1995   4  25  9:24:14   57.95  24.33  2.0    0.96  14.50      3    3    2  HFS    656   19
1995   4  25  9:28:50   58.25  12.48  1.0    3.54  11.98      9    4    2  HFS    221    8
1995   4  25  9:40:37   59.39  27.76  1.9    0.47   5.73      5    3    2  FIN    246   95
1995   4  25  9:55:08   61.19  21.84  1.6    0.50   2.65      2    2    1  FIN    228    9
1995   4  25  10:24:51  59.39  27.17  1.4    0.79   1.27      3    3    1  FIN    236   16
1995   4  25  10:29:51  66.35  12.85  2.4    2.22   6.67     18   10    5  NRS    629    7
1995   4  25  10:30:28  60.09  22.55  1.1    0.19   3.27      2    2    1  FIN    244   10
1995   4  25  11:25:07  67.55  20.39  1.6    1.23   9.08      4    3    2  ARC    304    9
1995   4  25  11:55:26  60.39  21.94  1.4    1.01   4.15      2    2    1  FIN    253   12

******** Last GBF Epicenter Update (GMT): 12.46
Last Update of this file (GMT):          Tue Apr 25 13:53
Last Update of this file (local time):   Tue Apr 25 15:53
```

Initial beam grid



Typical seismicity

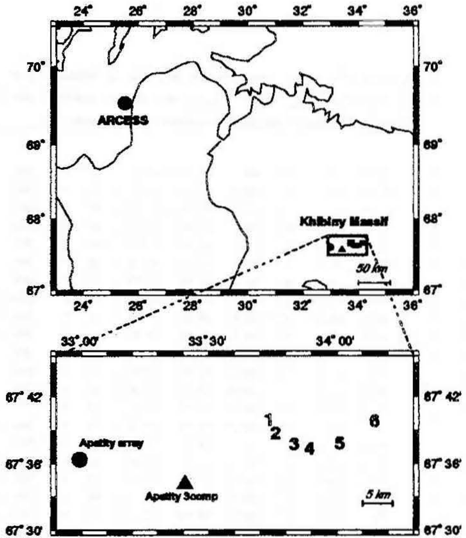


Detailed GBF solutions

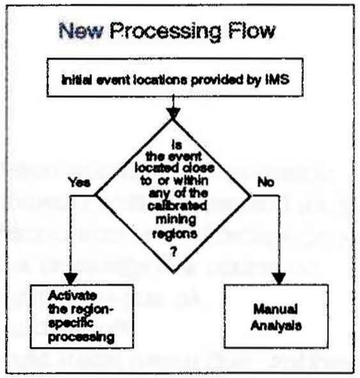
```
Origin time          Lat    Lon    Azres  Timres  Wres  Nphase Ntot  Nsta Netmag
 1995-115:10.29.51.0  66.35  12.85  6.67   2.22   3.89   10    18    5   2.36

Sta   Dist    Az    Ph  Time        Tres  Azim   Ares   Vel  Snr   Amp     Freq  Fkq Pol  Arid    Mag
NRS   629.8    5.4  Pn  10.31.16.5   0.7    7.5    2.1  8.1   7.4   346.6  4.52  1        776068
NRS   629.8    5.4  p   10.31.23.2          7.5    2.1  8.1   3.8   276.2  3.60  2        776072
NRS   629.8    5.4  Sn  10.32.27.1   4.3    8.2    2.8  4.2   2.7   702.8  4.23  4    3   776074  1.65
NRS   629.8    5.4  Lg  10.32.48.8   1.6  359.9   -5.5  3.7   3.7  1262.6  2.11  2   -2   776081  1.95
NRS   629.8    5.4  s   10.32.55.8         24.4   19.0  4.3   2.8  1865.5  2.84  1        776088  2.15
ARC   637.4  242.2  Pn  10.31.18.4   1.7  232.0  -10.2  9.4  12.2   231.0  4.78  2        776080
ARC   637.4  242.2  p   10.31.22.1        231.5  -10.7  8.9   3.7   467.1  6.46  1        776083
ARC   637.4  242.2  p   10.31.27.3        218.2  -24.0  7.9   2.6   389.6  8.43  3        776084
ARC   637.4  242.2  s   10.32.15.6        231.2  -11.0  5.3   5.1  2021.9  4.76  1   -2   776087  2.06
ARC   637.4  242.2  Sn  10.32.23.1  -1.3  229.4  -12.8  5.2   2.7  1447.7  5.05  2        776089  1.90
ARC   637.4  242.2  s   10.32.41.9        232.2  -10.0  4.1   2.6  1126.2  2.48  1        776090
ARC   637.4  242.2  Lg  10.32.47.4  -1.9  243.4    1.2  4.3   2.5  1380.9  1.81  1        776092  1.80
HFS   694.4  356.8  Pn  10.31.23.0  -0.6  345.1  -11.7  8.2   5.2    84.7  4.01  3        776069
HFS   694.4  356.8  Lg  10.33.06.3   1.0  353.7   -3.1  4.0   3.9   272.6  2.04  2        776073  2.28
HFS   694.4  356.8  s   10.33.12.2        352.6   -4.2  3.7   3.2   372.1  2.98  3        776079  2.48
FIN   847.1  315.9  Lg  10.33.45.9  -2.1  321.5    5.6  4.0   4.2   854.3  2.66  1   -2   776095  2.70
APA   887.5  270.3  s   10.33.07.4        279.7    9.4  3.4   4.8   303.8  4.16  3    2   776075
APA   887.5  270.3  Sn  10.33.10.1  -7.0  258.7  -11.6  4.4   2.8   316.0  4.29  3    2   776082  2.38
```

Fig. 7.1.5.

Automatic Post-Processing of Khibiny Events



Schematic map of the Khibiny Massif region of the Kola Peninsula of Russia, with its mining sites 1-6.

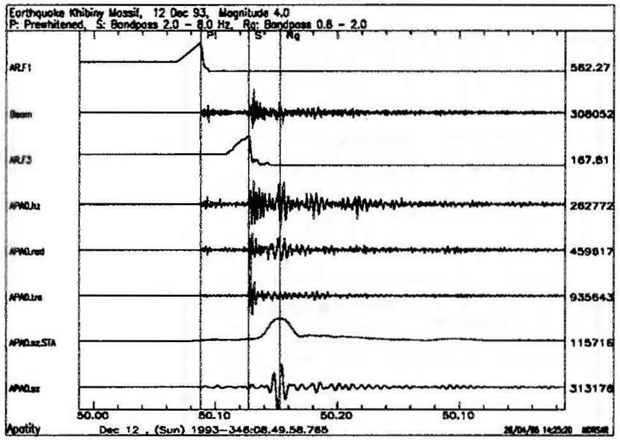


Schematic view of the principle behind the automatic post-processing of seismic events

Fig. 7.1.6.

Processing steps:

- P arrival time estimated by autoregressive method
- P azimuth estimated by broad-band f-k method for a fixed frequency band, using a fixed time window positioning
- Find maximum amplitude of Rg-phase
- Rg azimuth estimated by broad-band f-k method for a fixed frequency band, using a fixed time window positioning
- S arrival picking on the three-component instrument using the autoregressive onset time estimator



The seismograms of the figure are Apatity array recordings of an event from mine no. 1. The figure also shows likelihood functions (traces 1 and 3 from the top) used to estimate P and S arrival times, and an STA envelope (trace 2 from bottom) to estimate the peak of the Rg phase.

Improved Location Estimates