The Research Council of Norway (NFR)

NORSAR

NORSAR Scientific Report No. 1-94/95

Semiannual Technical Summary

1 April - 30 September 1994

Kjeller, November 1994

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

7 Summary of Technical Reports / Papers Published

7.1 A system for continuous seismic threshold monitoring, final report

Introduction

In the previous NORSAR Semiannual Technical Summary, we outlined the general approach and the implementation considerations of the continuous seismic threshold monitoring (CSTM) system (Kværna et al, 1994a). We have now completed the development, and we will in this report describe the automatic processing flow, outline the key functions of the interactive analysis, discuss the output produced by this system, and finally outline possible future modifications and extensions.

Processing flow

The CSTM system is logically divided into two parts; the continuous processing modules and the interactive analysis modules. A flowchart of the processing modules is given in Fig. 7.1.1, and comments on the different steps are given in the following.

The basis for all calculations are the diskloops with continuous seismic data from the network stations. Following the recording onto the diskloops, the seismic data for each station is subjected to beamforming (arrays only), bandpass filtering and short-term-average (STA) calculations. The continuous STA data are then stored onto new diskloops with a typical sampling rate of 1 Hz.

The STA data for each station is subsequently used for calculation of the network upper magnitude thresholds. In our previous report (Kværna et al, 1994a), we showed that the term log (A/T) in the magnitude relation can be well approximated by log (STA) multiplied by a constant that is specific for each instrument and bandpass filter. These constants are found from analysis of representative event segments, and for standard short-period instruments, these constants are often very close to the displacement response value at 1 Hz.

The calculation of network magnitude thresholds from a large number of stations (~50) is a computer intensive task. Using a sampling interval of 10 s and a global grid of 2562 targets, it took about 50 minutes to process 60 minutes of data on a Sparcstation 20 (60 MHz). In comparison, the computational load of the STA calculations for each station is rather low. The continuous network magnitudes for each of the nodes of the global grid system is written onto a new diskloop. These data are stored in demultiplexed form to facilitate fast read access for plotting of time series.

The final step in the processing flow is to interpolate and reformat the magnitude thresholds to multiplexed form. This makes reading of the threshold data for a given time very fast, and enables us to rapidly update displays of magnitude thresholds onto different types of map sections. The computational load of this module is modest compared to the calculation of the actual magnitude thresholds.

Interactive analysis

A detailed description of and examples from the different interactive analysis options are given in the Continuous Seismic Threshold Monitoring User's Guide (Kværna et al, 1994b), that is available from NORSAR upon request. A schematic overview of the functionality of and the interaction between the different interactive analysis modules is shown in Fig. 7.1.2.

- **The TM trace displayer:** The main function of this module is to display time-series of magnitude thresholds for given target regions. The selection of targets can be done from the trace displayer itself, or alternatively, from interactive selection of targets using the TM map overlay module. The traces can be plotted normalized or on a fixed scale, such that time intervals with high thresholds stand out clearly.

  Events from various bulletins can also be shown. The main purpose of this option is to associate increased thresholds with signals from actual events.

  For a quantitative assessment of the magnitude thresholds, displays of both peak statistics and cumulative distributions are available.

- **The TM map overlay module:** In order to show how the magnitude thresholds vary as a function of geographical position, we have the possibility to display colored snapshots of the magnitude thresholds onto various map sections. A large selection of predefined map sections are already available, and new sections can easily be generated.

  The time of the snapshot can be set from the TM map overlay module itself, or alternatively, from interactive cursor control using the TM trace displayer. This interaction allows us to investigate the time-space variation of the magnitude thresholds, and is therefore a valuable tool for identifying time intervals and regions with increased thresholds. To further investigate the cause of the increased thresholds, located events can be plotted onto the maps for a predefined time interval around the origin time of the events.

  An example of global magnitude threshold variations during the occurrence of a major earthquake is given in Fig. 7.1.3.

  After interactively selecting a time interval on the trace displayer, we also have the possibility to sequentially update the colored magnitude thresholds within the selected time interval. This kind of animation can be very instructive to understand how increased noise levels and seismic events influence the global magnitude thresholds.

  Another option of the TM map overlay module is to update the colored thresholds at regular intervals, with a given lag behind real-time (e.g., one hour). This lag is necessary to accommodate the arrival of phases with the largest travel-times, as well as the time needed to process the data. With a modification to the algorithm for threshold calculations, this function can be used for a continuous assessment of the detection capability of the network.

- **The World Map:** One purpose with this module is to show the station distribution of the network used in the calculation of the magnitude thresholds. Another application is to display the location of events in the available bulletins. On the TM trace displayer we may interactively select events and by using inter-process communication we may plot the events onto the world map.

Interpretation of derived magnitude thresholds

We have noticed that there have been some misunderstandings on the interpretation of the magnitude thresholds computed by the CSTM system. It is important **not** to consider the values as a 90 per cent network detection threshold, since we have not taken into account a signal-to-noise ratio which would be required in order to detect an event.

However, if we exclude the time intervals where our network actually detected and located an event in the target region, we may use the following interpretation:

"We are confident (at the 90 per cent level) that no events larger than the calculated thresholds occurred in the area".

Practical monitoring of a given target region (e.g., of a 24 hour time interval) should be done in the following way:

- Check to see if the network bulletin has reported any events located in the target region. If so, identify the threshold peaks associated with the located events.

- Attempt to associate the largest peaks in the threshold trace to events located outside the target area. In theory, it may have been possible that an explosion in the target area could have been hidden in the coda of the interfering event, but this requires that the origin time of the explosion coincided with the time of the threshold peak. However, due to the short time periods with significant threshold peaks, the probability of such a coincidence is very small. For further discussion on this topic, see Kværna (1992).

- Use the threshold trace to determine a magnitude reference level for which all exceedances are caused by signals from known events. We may then conclude: We are confident (at the 90 per cent level) that no events larger than the magnitude reference level occurred in the target region during this time period.

In this way, the analyst can rapidly get an assessment of the possible seismic activity in the target region during the given time interval. This will also enable him to focus his analysis on the short time intervals when "real" evasion opportunities exist.

Uncertainty considerations

Generic global attenuation and travel-time curves form the basis for the network magnitude calculations (see Figs. 7.1.4a and 7.1.4b). As is well known, the attenuation curves are accompanied with significant uncertainties. E.g., the studies made on P-wave amplitude variability (Veith and Clawson, 1972; Lilwall, 1986; Ringdal and Fyen, 1979) indicate a standard deviation of 0.35-0.40 magnitude units. If reliable regional corrections are available, the uncertainty can be reduced somewhat. In the calculation of the network magnitude thresholds, these uncertainties are taken into account.

There are also other factors in the calculation of magnitude thresholds that are associated with uncertainties. These are:

- The use of log(STA) as a representation of log (A/T)
- The effect of beamforming, filtering and different instrument responses on the seismic amplitude
- Instrument calibration
- The effect of each target point representing a finite geographical area.

We have during our development of the CSTM system used the strategy of being conservative with respect to the estimation of upper magnitude thresholds. Missing information on the exact values of the different parameters are therefore compensated for by assuming conservative values or by increasing the uncertainty. With this in mind, it is obvious that the quality of the output from the CSTM system can be significantly improved. By conducting additional studies, more precise estimates of the parameters and their associated uncertainties can be obtained, and we can thereby lower the derived magnitude thresholds and/or increase the degree of confidence.

Future improvements

The by far largest uncertainties involved in the magnitude threshold calculations are associated with the use of generic global attenuation relations. Ideally, one would for each network station like to derive regionalized attenuation curves for the entire globe, but this is an extremely complex undertaking that is unlikely to be done in the near future. There are, however, some improvements that can be made without such extensive efforts.

First of all, known station biases should be taken into account. We are especially worried about stations with large negative biases, because this may give rise to unrealistically low magnitude thresholds. Along the same lines, we would for each station like to identify and introduce corrections to regions with very extreme amplitude anomalies. Also in this case, the large negative biases cause the largest problems.

It should be emphasized that the calculation of network magnitude thresholds is not an averaging process, but is very sensitive to outliers in the population of individual station magnitude estimates. For a large network of more than 50 stations it may often happen that some of the stations are not operating properly, e.g., due to low gain. For such a large network it may be necessary to introduce an additional outlier rejection algorithm before calculating the actual magnitude thresholds.

On the other hand, this sensitivity to outliers can be used as a quality control of the stations in the network, and this application should be explored further.

The program module calculating the STA data for each station is a modified version of the detector program (DP) program developed at NORSAR. When intervals with bad data occur (spikes, gaps, clipped data, calibration signals), we have already procedures in place that take actions that are sufficient for operating a detector. However, for computing of threshold magnitudes, we should not allow any bad data to be included at all. It is therefore necessary to implement additional routines that identify all time intervals with bad data for any given station, such that all these intervals can be discarded from further processing for that station.

Both the relation between log (STA) and log (A/T) and the signal loss due to beamforming and filtering have turned out to vary among the different seismic stations. In order to obtain precise estimates of the relations, we have to analyze a representative number of events for each station in the network. In the current version of the CSTM system, we have only used conservative generic relations, and even a limited effort of analyzing only 3-5 events per station would significantly improve the precision of the magnitude threshold estimates.

As explained earlier in this report, the derived magnitude thresholds should not be interpreted as a 90 per cent network detection threshold. But by modifying the algorithm to take into account a predefined signal-to-noise ratio (SNR) as well as the number of stations required to detect an event, the maps generated by the CSTM system can be made very similar to the standard capability maps produced by programs like SNAP/D or Networth.

Conclusions

The main focus during the development of the CSTM system has been to develop an environment that facilitates both real-time operation as well as testing of new ideas in the context of continuous seismic threshold monitoring. The current operational system is not fully optimized with respect to processing parameters, but the framework for a stepwise improvement exists. We can as of today demonstrate the potentials of using continuous seismic threshold monitoring as a part of a global seismic verification system, but some caution has to be taken during the interpretation of the derived magnitude thresholds. Further improvements will rely heavily on the possibility of conducting extensive event analysis and associated calibration efforts.

T. Kværna
F. Ringdal
H. Iversen
N.H.K. Larsen

References

Kværna, T. 1992: Continuous seismic threshold monitoring of the northern Novaya Zemlya test site: Long-term operational characteristics, Sci. Rep. No. 12, PL-TR-92-2118, Phillips Lab., Mass., USA.

Kværna, T., F. Ringdal, H. Iversen and N.H.K. Larsen (1994a): A system for continuous global seismic threshold monitoring, Semiannual Tech. Summary, 1 Oct 93 - 31 Mar 94, NORSAR Sci. Rep. No. 2-93/94, Kjeller, Norway.

Kværna, T., H. Iversen and N.H.L. Larsen (1994b): Continuous Seismic Threshold Monitoring User's Guide, NORSAR, Kjeller, Norway.

Lilwall (1986): Empirical amplitude-distance / depth curves for short-period P waves in the distance range 20 to 180°, AWRE Report No. O 30/86.

Ringdal, F. and J. Fyen (1979): Analysis of Global P-wave Attenuation Characteristics using ISC data files, Semiannual Tech. Summary, 1 Apr - 30 Sep 1979, NORSAR Sci. Rep. No. 1-79/80, Kjeller, Norway.

Veith, K.F. and G.E. Clawson (1972): Magnitude from short-period P-wave data, *Bull. Seism. Soc. Am.*, 62, 435-453

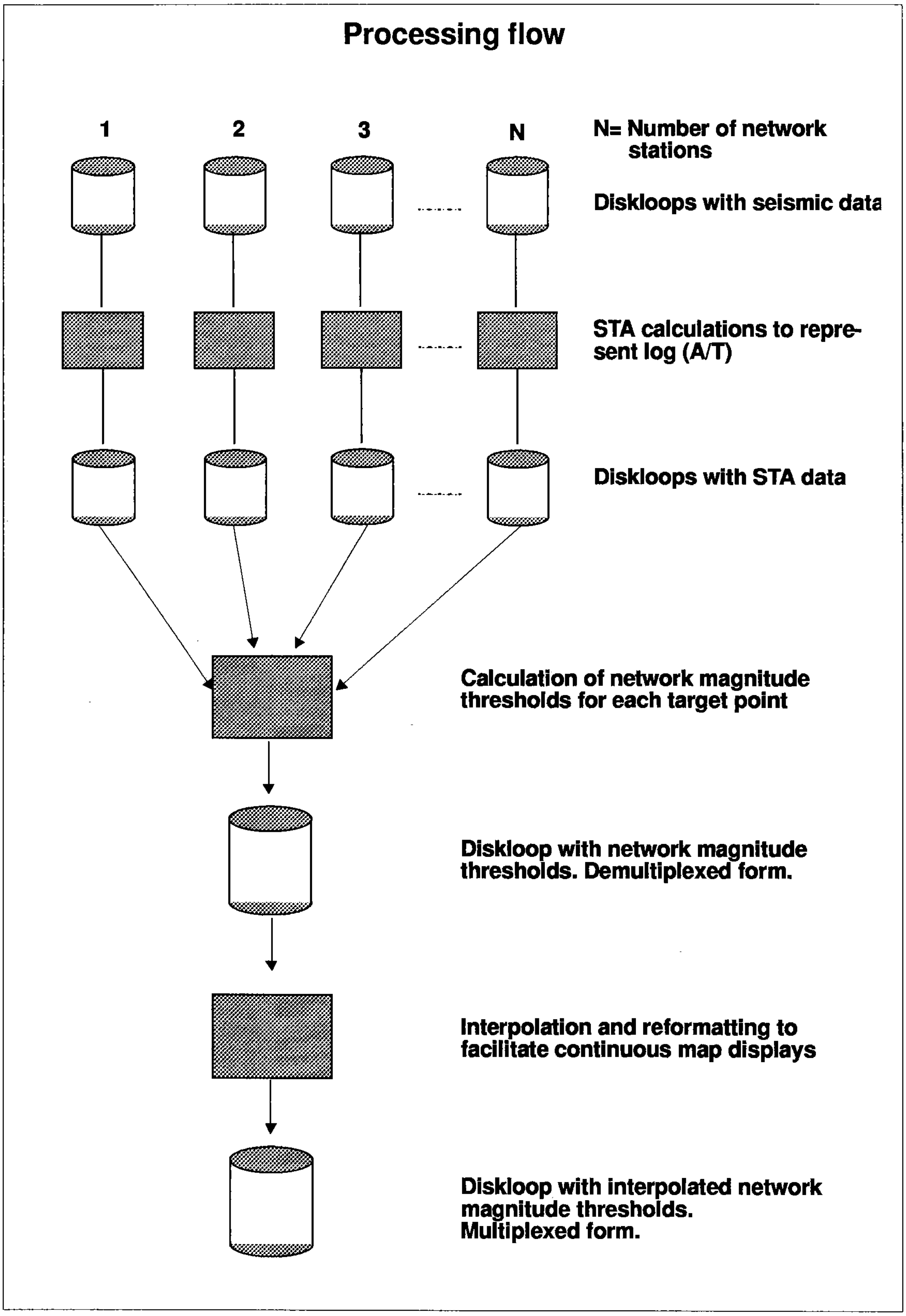

Fig. 7.1.1: Flowchart showing the structure of the continuous processing flow of the CSTM system

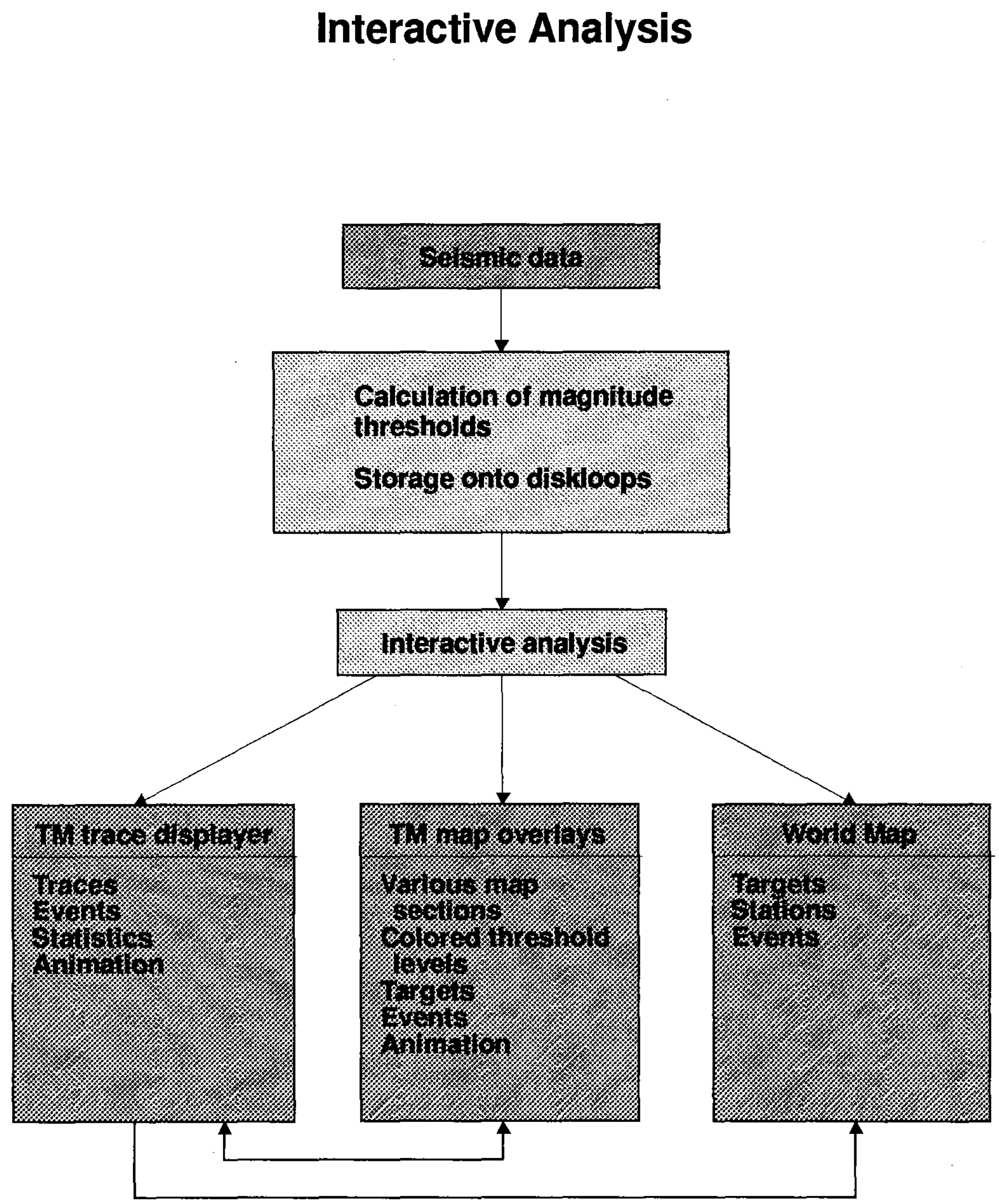

Fig. 7.1.2: Flowchart describing the functions of and interaction between the interactive modules of the CSTM system.

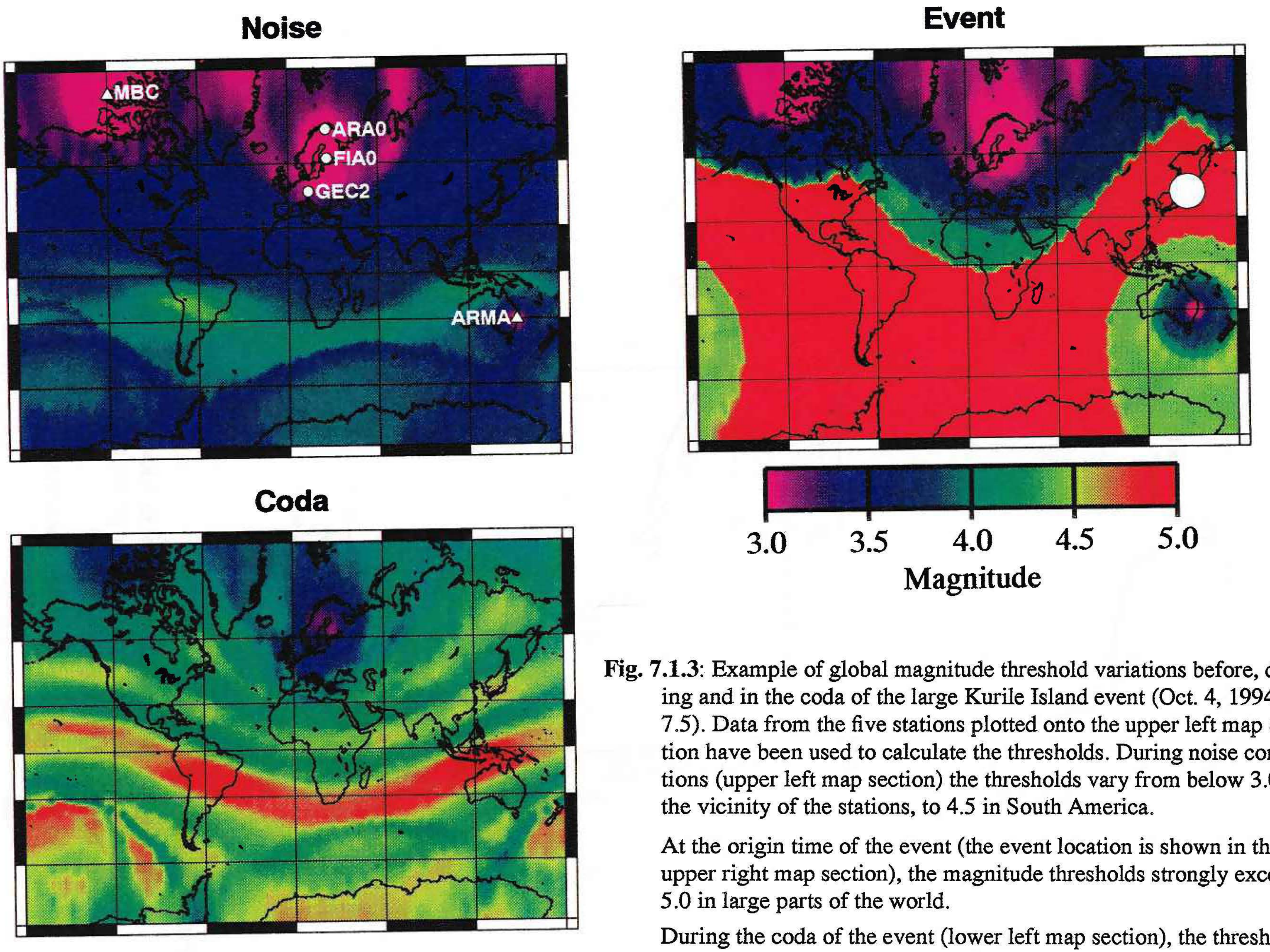

Fig. 7.1.3: Example of global magnitude threshold variations before, during and in the coda of the large Kurile Island event (Oct. 4, 1994, m_b 7.5). Data from the five stations plotted onto the upper left map section have been used to calculate the thresholds. During noise conditions (upper left map section) the thresholds vary from below 3.0 in the vicinity of the stations, to 4.5 in South America.

At the origin time of the event (the event location is shown in the upper right map section), the magnitude thresholds strongly exceed 5.0 in large parts of the world.

During the coda of the event (lower left map section), the thresholds start to fall back to normal (e.g., in Northern Europe).

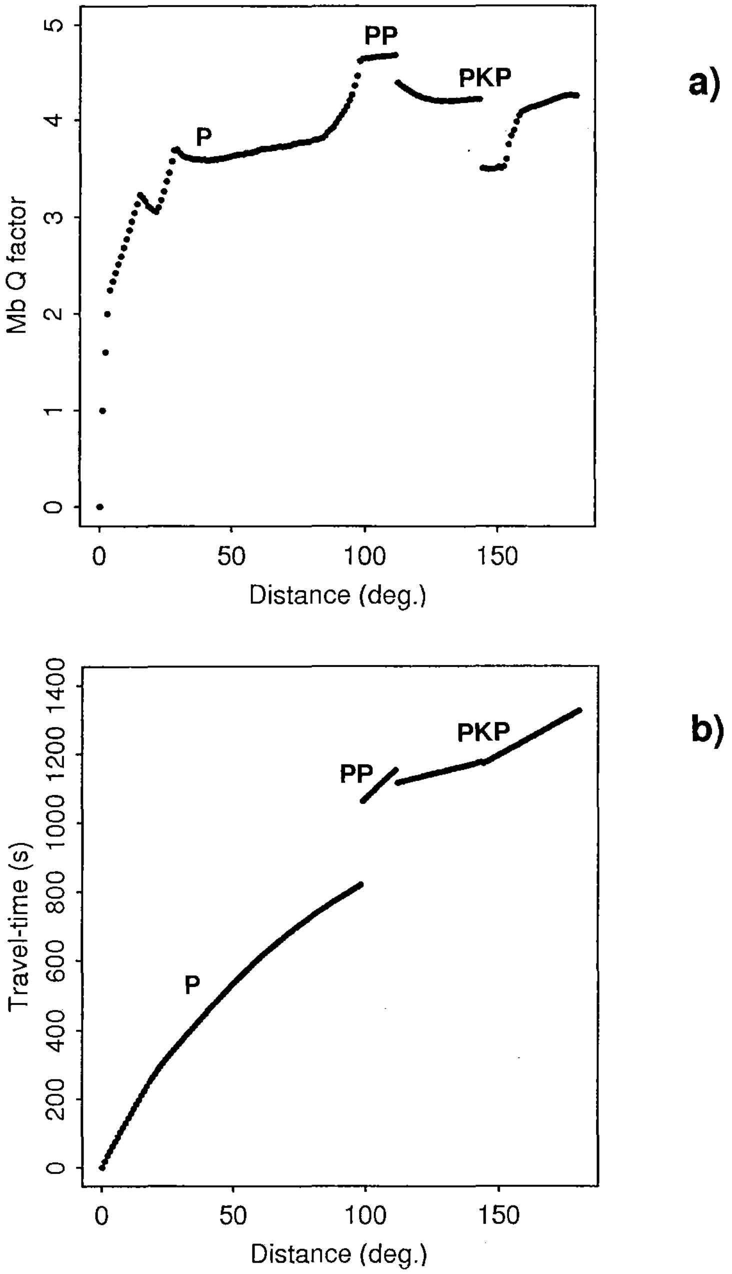

Fig. 7.1.4

a) Global m_b attenuation relations used to calculate the magnitude thresholds. Notice that relations for three different phases (P, PP and PKP) have been used to span the 0 - 180 degrees distance range.

b) Travel-times of the phases used for magnitude threshold calculations.