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7.8 Continuous threshold monitoring using "regional threshold displays"

Introduction

Continuous threshold monitoring (Ringdal and Kværna, 1989) is a method of monitoring seismic amplitude levels for the purpose of assessing the largest size of events in a given target region that might go undetected by a monitoring network. The method has recently been implemented within the Intelligent Monitoring System (IMS) (Bache *et al*, 1990). In previous Semiannual Technical Summaries, as well as in the present issue, several examples of application have been presented. In particular, Kværna and Ringdal (1990) conducted a one-week monitoring experiment of the Novaya Zemlya test site using the Fennoscandian regional array network, and concluded that continuous threshold monitoring down to event size as low as $m_b = 2.5$ appeared feasible for this site.

Regional threshold monitoring

In the current IMS implementation of the TM technique, a limited number of specific target sites are monitored. These sites include several mines in Scandinavia and Western Russia, along with the Novaya Zemlya and Semipalatinsk nuclear test sites. For each of these sites, a number of calibration events are available, and thus it has been possible to fine tune the parameters in order to obtain close to optimum monitoring performance.

"Regional threshold monitoring" is defined as an extension of the original "site-specific" threshold monitoring concept. It entails using the same basic principles to obtain wide geographical coverage, including coverage of regions for which no calibration events are available. The key to achieving this is to develop "generic" relations for attenuation and magnitude corrections of seismic phases of interest, and to deploy a sufficient number of beams to ensure adequate geographical coverage.

Kværna (1991, this issue) has developed initial such generic relations for the Pn and Lg phases of NORESS, ARCESS and FINESA. His relations are applicable to Northern Europe and adjacent regions, and are based on a systematic analysis of several hundred phase observations of regional events in various geographical areas. Kværna's results form the basis for the study presented in this paper.

Threshold maps

The regional threshold monitoring approach lends itself naturally to displays in the form of contoured geographical maps. By using a spatial grid covering the area of interest, interpolation can be applied to get a visual representation of threshold variations over an extended geographical region, and examples will be given later.

These contour maps are in many ways similar to the standard network capability maps traditionally used in seismic monitoring studies (Networth, Snap/D, etc.). However, there are some fundamental differences:

- Standard capability maps use as a basis statistical models of signal and noise characteristics; in particular a signal variance and a noise variance is assumed to compensate for statistical fluctuations. In contrast, the regional TM maps give "snapshots" of the capability as actually observed at a given point in time.
- With standard maps, no allowance is made for unusual conditions, such as, e.g., the occurrence of a large earthquake or an aftershock sequence which may cause the network capability to deteriorate for hours. With the TM approach, the actual variation in detection capablity is immediately apparent.
- Standard capability maps require assumptions, e.g., with regard to "SNR threshold required for detection" and "minimum number of stations required to locate". The TM maps require no such assumptions since they are not tied to "detecting and locating" seismic events, but rather describe directly the observed "seismic field" at any point in time.

We will briefly comment further on the last item mentioned above: The requirement of multistation detection with the standard method will sometimes result in unrealistically high thresholds, e.g., in areas near a station of the monitoring network. The multistation requirement also implies that the method is not able to adequately represent the possibility of particularly favorable source-station paths. A case in point is the outstanding capability of the NORESS array in detecting explosions at Shagan River. Thus, if NORESS has no detection, it is highly unlikely that any explosion at that site of $m_b > 3$ has occurred, whereas a capability map based on 4-station detection requirement may well show a threshold an order of magnitude higher.

The threshold monitoring approach will avoid these inconsistencies. Thus, under normal noise conditions, the thresholds will be very low within a few hundred km of each network station. Furthermore, since the TM thresholds are dominated by the "best" station of the network, particularly favorable source/receiver paths may be accommodated, although this would require a combination of regional and site-specific monitoring.

Display examples

Using the generic relations developed by Kværna (1991), we computed a threshold monitoring grid of 20 x 20 geographical aiming points for a 40-minute time interval. Data from the three arrays NORESS, ARCESS and FINESA were used. Contouring maps were developed by interpolation in this grid, and displayed in the form of color maps where the color scale is tied to the actual threshold.

Figs. 7.8.1 and 7.8.2 show two representative examples of output from this procedure.

Fig. 7.8.1 shows the "absolute" TM threshold levels (with m_b units indicated on the color template) at a specific time during a typically "quiet" period (i.e., no seismic event occurring). We note that the areas immediately surrounding each array (deep or light blue) show the lowest thresholds (below $m_b = 0.5$), whereas most of the remaining area at regional distances has a green color, indicating thresholds in the range $m_b = 0.5–1.5$. The yellow color seen further away from the network stations indicates thresholds of 1.5 to 2.5.

Fig. 7.8.2 shows a typical map at a time corresponding to a mining explosion (magnitude 2.2) at the Apatity mine in the Kola Peninsula. In contrast to Fig. 7.8.1, we have here chosen to display *relative* thresholds (i.e., thresholds relative to the average thresholds during noise conditions at each geographical point). This is done to emphasize more clearly the effects of the seismic event in causing threshold increases outside the source area. We note that, naturally, the area surrounding the mining site has the highest relative threshold (red), whereas the "side lobe" effect causes significant threshold increase also in other regions, some of which quite far apart from the mine.

The computer displays shown in Figs. 7.8.1 and 7.8.2 also include fields for displaying threshold traces and selecting various plotting options. At the present time, however, these features have not been operationally implemented.

Perspectives

We consider that the regional approach to threshold monitoring would imply a significant enhancement of practical monitoring of underground nuclear explosions. In particular, a graphics display system could be developed to provide the analyst with very useful interactive tools. Among features that might be desirable are:

- "Snapshots" of regional threshold maps taken at times when a peak occurs on a threshold monitoring trace. For example, if a peak is observed on the threshold trace used to monitor Novaya Zemlya, such a snapshot could immediately reveal that this peak might, e.g., be a side lobe effect from a remote earthquake.
- Threshold displays taken during the coda of very large earthquakes, indicating the resulting effects on detectability in various regions.
- "Cumulative" displays showing the largest possible events that might have occurred during a given time period (e.g., 24 hours).

- Combinations of threshold displays and conventional epicenter maps of detected events.

An extremely interesting application would be a real time "video" display of how the threshold situation fluctuates with time. When a seismic event occurs, a real time display of this type would illustrate how the threshold first increases at "side lobe" locations, with subsequent focusing upon the actual epicentral area. Such a video option could of course just as easily be implemented for off-line (retroactive) display of time periods of interest.

In order to make effective use of the regional threshold monitoring approach and the associated display options, a workstation with powerful computational and graphical capabilities will be required, and we are currently evaluating possibilities in this regard. We are also continuing our research aimed at integrating the "regional" and "site-specific" threshold monitoring methods, which we consider to have a combined potential of becoming a basic tool in practical monitoring applications.

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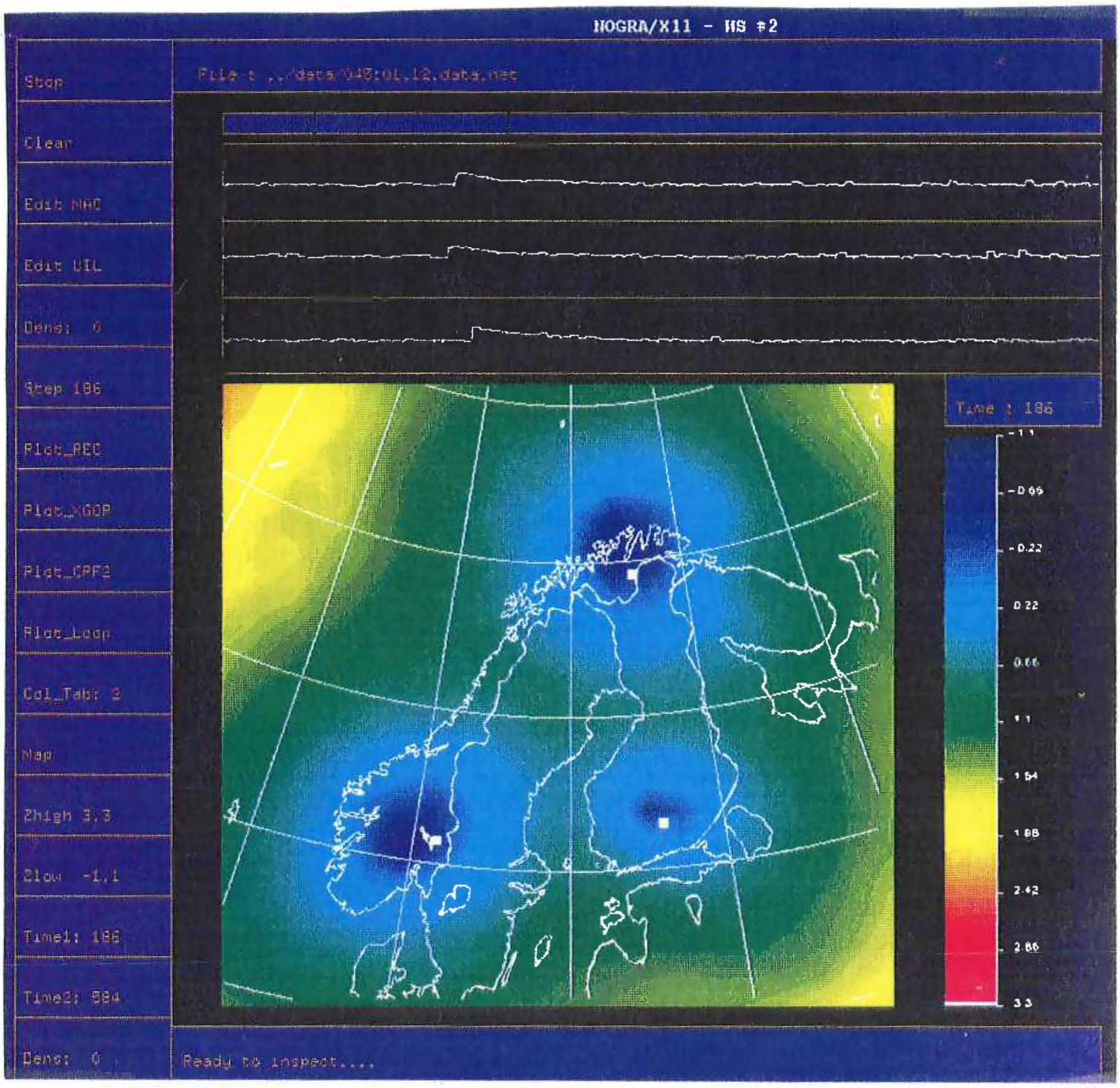

Fig. 7.8.1. Example of regional threshold display of "absolute" threshold levels, at a typical "quiet" period. See text for detailed explanation.

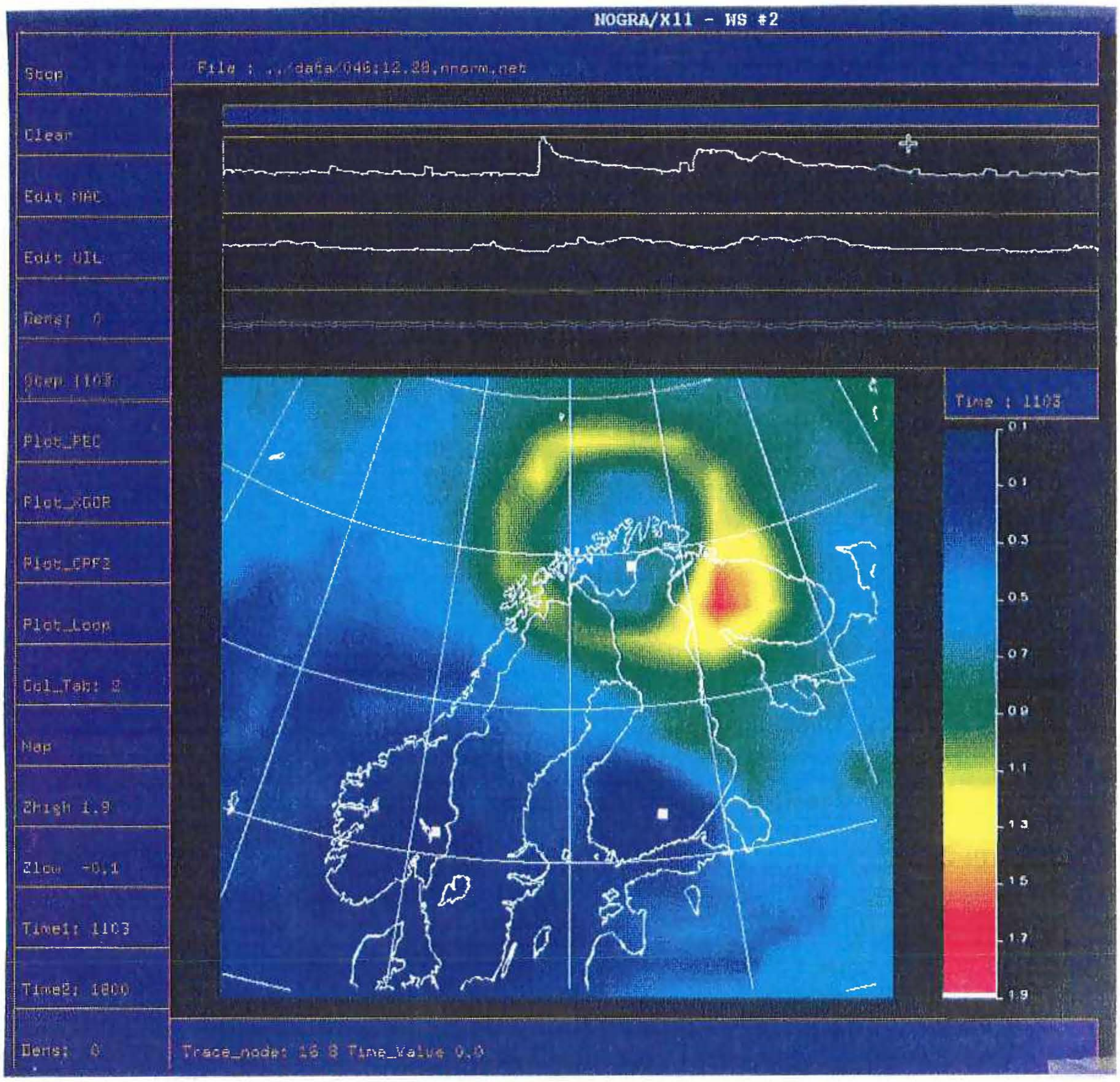

Fig. 7.8.2. Example of regional threshold display of "relative" threshold levels at a time when a mining explosion occurred in the Kola Peninsula. See text for detailed information.