NORSAR

Seismological Verification of a Comprehensive Nuclear Test Ban

Norwegian Seismic Array (NORSAR)
25th Anniversary
15 June 1993

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Norwegian Seismic Array

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Royal Norwegian Ministry of Foreign Affairs

Foreword

An effective system of verification is of utmost importance in any international arms control and disarmament agreement. For a Comprehensive Nuclear Test Ban Treaty (CTBT), international cooperation in the exchange and analysis of seismic data will form a principal tool for ensuring adequate verification.

Norway has consistently supported the work of the Conference on Disarmament's Group of Scientific Experts in developing a global seismological system to assist in the verification of a CTBT. The seismological facilities in Norway today are among the most advanced in the world, incorporating the most recent scientific and technological achievements. In particular, the new seismic array technology described in this document holds promise to significantly improve the effectiveness of a global seismic verification system.

The picture on the cover page was taken at the ARCESS array site in Finnmark, northern Norway, on August 29, 1986.

Nuclear Test Ban Verification

To achieve a Comprehensive Nuclear Test Ban Treaty (CTBT) has been a major aim of international disarmament negotiations for more than three decades. The Limited Test Ban Treaty of 1963 prohibited nuclear explosions in the atmosphere, in outer space and under water. The treaty did not comprise underground nuclear tests since the verification possibilities were not seen as adequate at that time.

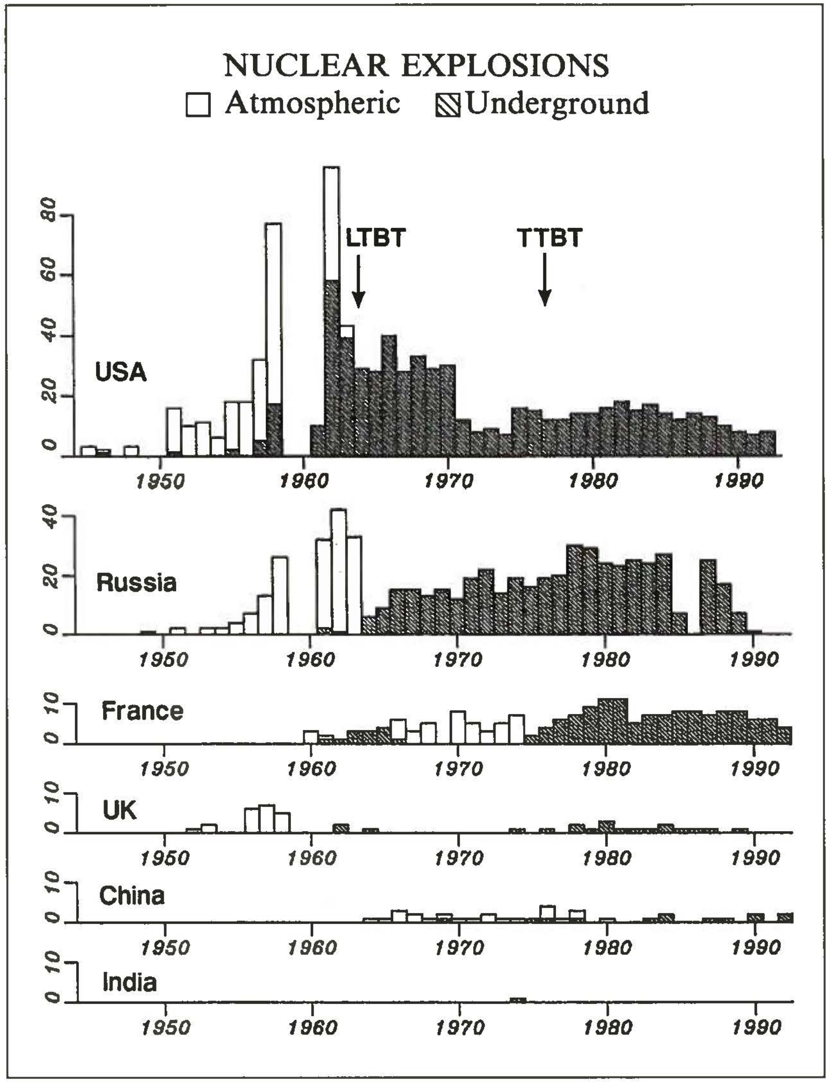
A verification system for a CTBT must be able to ensure, at a politically acceptable level, compliance with the agreements and to provide a credible deterrence against potential violations. An important function of such a system will be to build confidence that a treaty is adhered to through extensive international consultation and cooperation.

It is no coincidence that the science of seismology has had a central position throughout the negotiations of verification procedures for a CTBT. In fact, at a distance from the source, a nuclear explosion conducted underground can only be detected by recording the pressure waves that are generated, and that propagate through the earth in the same way as seismic waves generated by earthquakes.

After the Limited Test Ban Treaty of 1963, most of the nuclear weapon states have conducted their weapons tests underground, and testing in this environment causes by far the most difficult verification problems.

Norwegian Contributions

Norway has over the years devoted considerable resources to conducting seismological research in areas relevant to CTBT verification, in particular in support of the multilateral efforts within the Conference on Disarmament in this field. Research and developments at the Norwegian Seismic Array (NORSAR) have formed a key element in this regard, as described in the following.

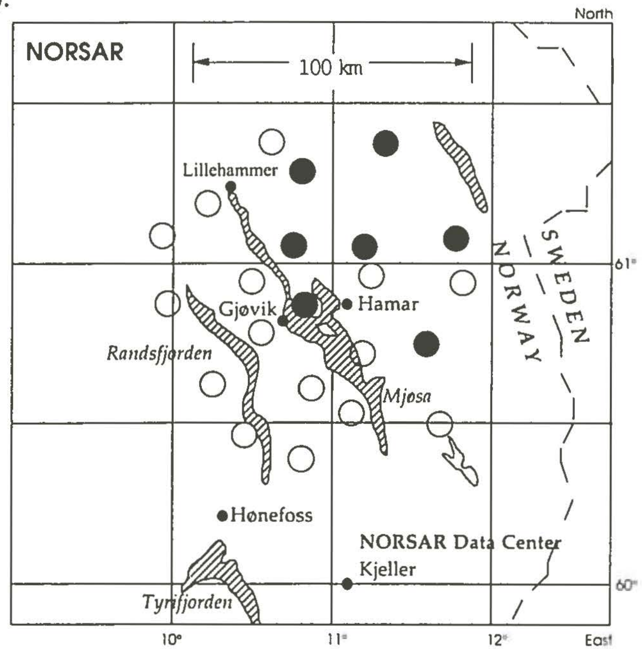


Annual number of nuclear explosions conducted by six countries. Note that the Limited Test Ban Treaty (LTBT) of 1963 did not significantly reduce the number of tests, but merely caused the signatories to conduct their testing underground. The Threshold Treaties (TTBT and PNET) of 1976, limiting the size of nuclear explosions to 150 kilotons TNT, did contribute to reduce the yields, but not the number of nuclear test explosions.

The NORSAR Observatory

The establishment of the NORSAR observatory dates back to the signing in 1968 of a Government-to-Government agreement between Norway and the United States concerning seismological research and development. NORSAR construction was completed in 1970, at which time the array comprised almost 200 seismometers deployed in a spatial pattern over an area of about 100 km in diameter.

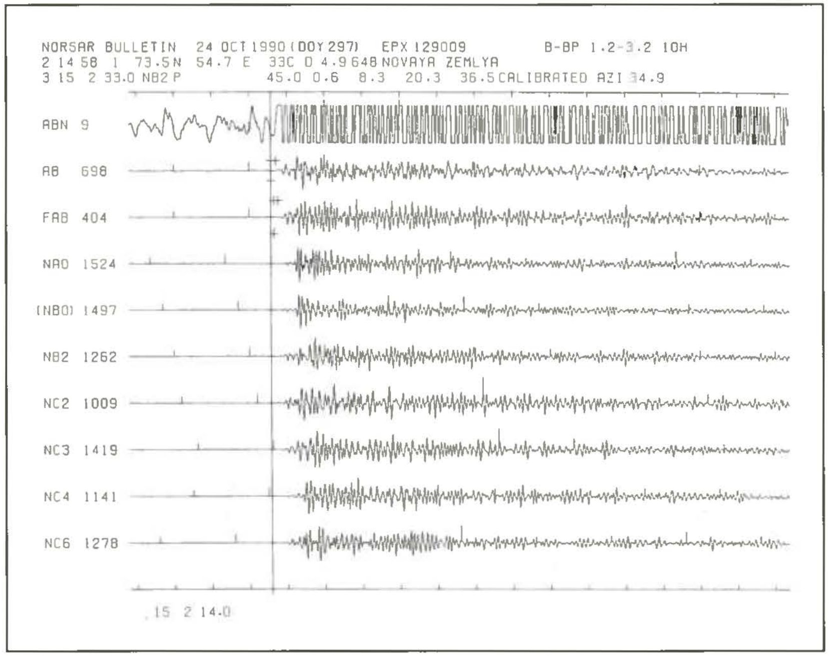
Acting as a huge antenna, the NORSAR array is able to focus on signals from seismic events in various regions of the earth, and then locate these events as well as suppressing "noise" disturbances originating from other sources (e.g., wind, sea waves and industrial activity).



The NORSAR array is located in southeastern Norway as shown in the figure. The array comprises 22 subarrays, 7 of which are currently in operation (filled circles). Data from the subarrays, which each consists of 9 seismometers, are transmitted to a data center at Kjeller for subsequent analysis.

The NORSAR observatory is administered by the Research Council of Norway (NFR). NORSAR is today one of the world's largest and most advanced seismological observatories. The array is situated in a favorable geological area, well removed from major earthquake zones, and its event detection capabilities are excellent for most of the northern hemisphere. For many regions of the world, the NORSAR detection performance is unsurpassed today. Research work at NORSAR is continually being conducted toward even further improving system capabilities.

At the time of NORSAR's 25th anniversary, a refurbishment program is underway to equip the array with the most advanced instrumentation currently available.



The NORSAR processing system provides automatic detection and location of earthquakes and nuclear explosions worldwide. The figure shows automatic processing results for a nuclear explosion at the test site at Novaya Zemlya, Russia.

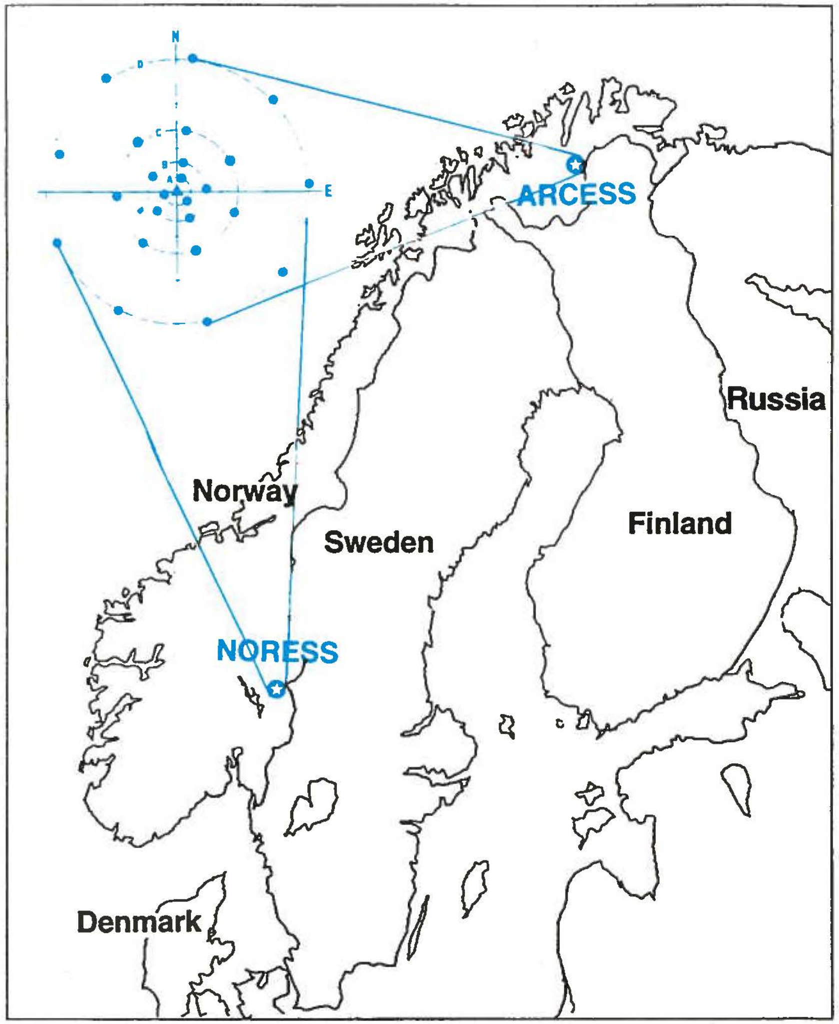
The Regional Array Concept

The regional array concept represents one of the major advances in recent years in the field of seismological verification. Norwegian and United States scientists have collaborated to develop the most advanced system in the world for remotely detecting, identifying and characterizing underground nuclear explosions.

The NORESS array (Norwegian Regional Seismic Array System), comprising advanced field installations as well as sophisticated data processing techniques, was established in southern Norway in early 1985. In June of that year, the Norwegian Ministry of Foreign Affairs hosted a Workshop in Oslo presenting the NORSAR/NORESS facilities in the context of seismological CTBT verification. Representatives of member and observer delegations to the Conference on Disarmament as well as scientific experts were invited to the Workshop, which was attended by 84 participants from 41 countries.

The geometric design and technical characteristics of the NORESS array are aimed at obtaining high detection performance for low-yield underground explosions at distances up to 3000 km. The seismometers are spaced in a pattern so as to ensure optimum performance over a wide range of signal frequencies, in particular the high-frequency signals commonly generated by underground nuclear explosions.

Given its successes, NORESS emerged as the potential prototype for a possible network of regional seismic arrays. The first step in establishing such a network was to construct a NORESS-type array at a distance of about 1,100 kilometers from NORESS. The Arctic Experimental Seismic Array System (ARCESS), located in Finnmark, northern Norway, was completed in 1987. Since then, several more arrays of similar type have been installed in northern and central Europe.

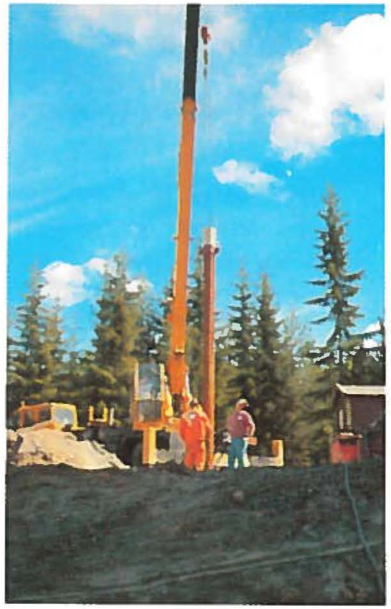


The two Norwegian regional arrays NORESS and ARCESS are situated approximately 1,100 km apart. Their geometric patterns are identical, each comprising 25 seismometer sites deployed in concentric rings over an area approximately 3 km in diameter.

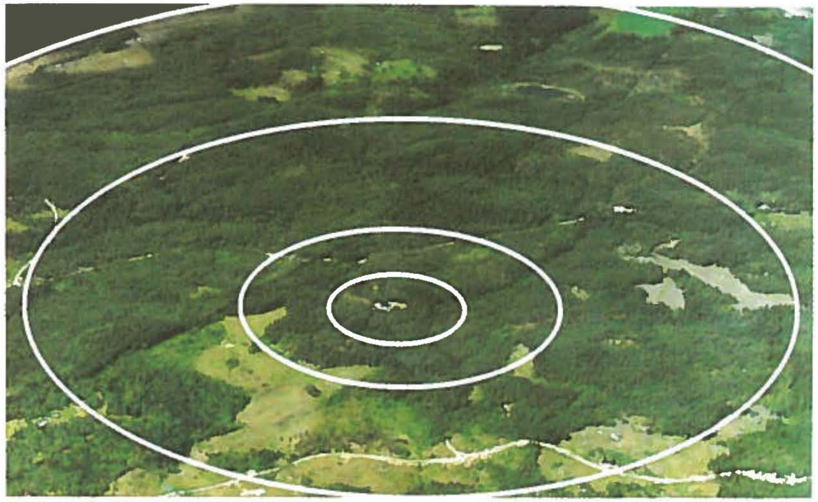
The Field Systems

Among the features that make the NORESS/ARCESS arrays exceptional are their automatic field operation, requiring only occasional visits for maintenance; the transmission of seismic information to distant receiving stations in real time; automatic self-calibration; exceptional reliability and high quality of the data; and automated signal processing methods.

Short-period seismometer designed to respond to the most detectable signals from underground explosions. The instrument is approximately 38 cm long.



Borehole instruments being installed at the array center site to record ground motions in the east-west, north-south, and vertical directions.



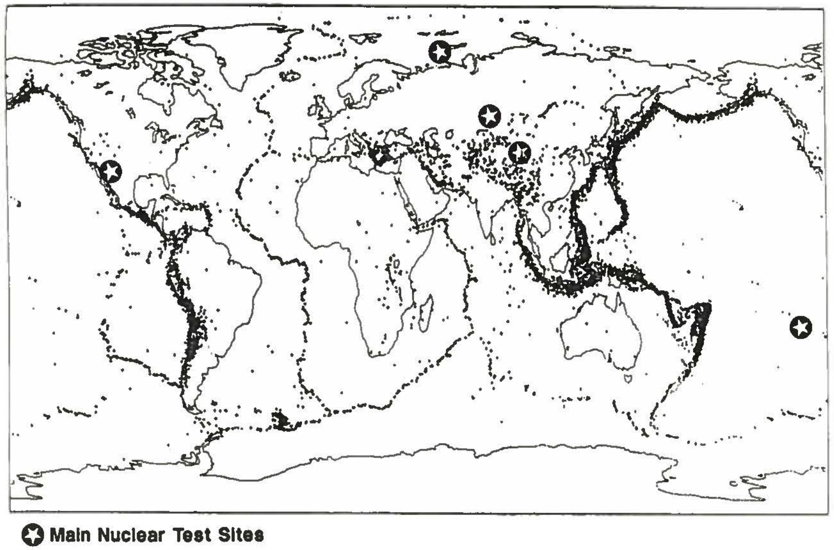
Site of the NORESS array. Seismometers are deployed on concentric circles. Data from all seismometers are cabled to the central site, where they are transmitted to the data processing center at Kjeller, Norway.

The ARCESS central field station houses instruments that provide power, timing signals and calibration commands to all instruments in the array. Data from the array seismometers are collected and transmitted by satellite to the NORSAR Data Center at Kjeller.

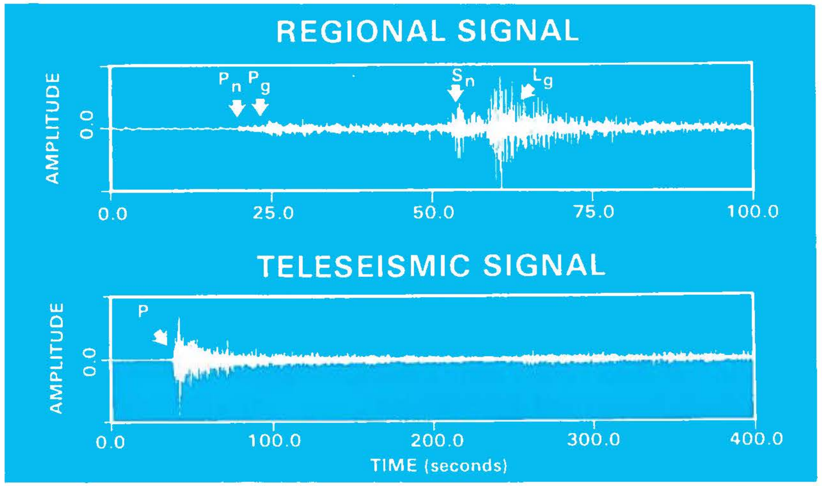
Detecting Nuclear Explosions

An important attribute of seismic arrays is their ability to detect very weak seismic signals that are submerged in background noise. This is done by processing the data using advanced computer algorithms. Signals from all seismometers are combined in ways that enhance the seismic signals of interest, while suppressing the noise. This is especially important for verifying a comprehensive test ban treaty because the ability to detect signals from low-yield tests, or tests conducted under conditions that muffle the signals, often has been cited as a main difficulty in ensuring reliable verification.

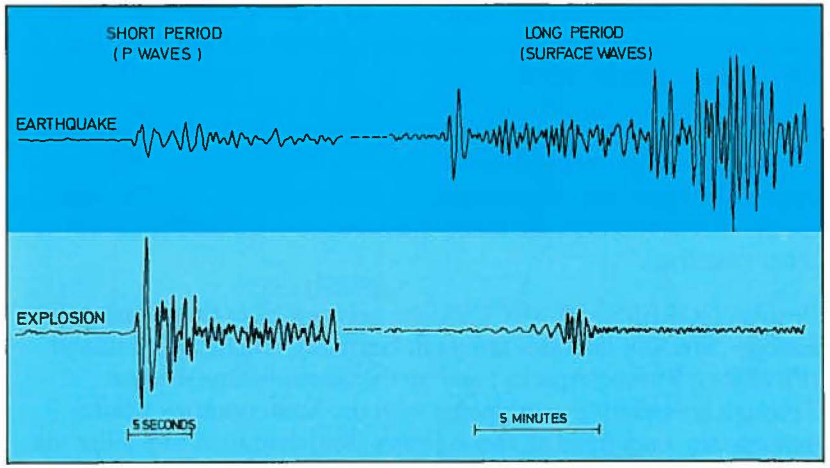
Another key problem in seismic verification is to reliably distinguish the seismic recordings originating from underground nuclear explosions from those produced by other sources, especially earthquakes. The many thousands of earthquakes occurring world-wide each year pose a formidable problem in this regard, and reliable source identification becomes particularly difficult as the size of the event decreases. Again, seismic arrays are especially well suited to handle these small events, and thus become essential also in a source identification context.



Earthquake occurrence world-wide (above magnitude 4.5) for a seven-year period.



The signals recorded at a seismograph station show different characteristics depending upon the distance from the source. At regional distances (less than 3000 km), the signals are complex in nature, whereas teleseismic signals (distance 3000-9000 km) are much simpler.



Seismic signals are recorded both from earthquakes and underground explosions. As shown on the figure, a typical earthquake signal (top) and an explosion signal (bottom) have different characteristic features, which may be used to discriminate between these two types of sources.

The Intelligent Monitoring System (IMS)

The Intelligent Monitoring System represents a new generation of seismic data analysis technology designed to exploit the full potential of a network of sensitive regional arrays.

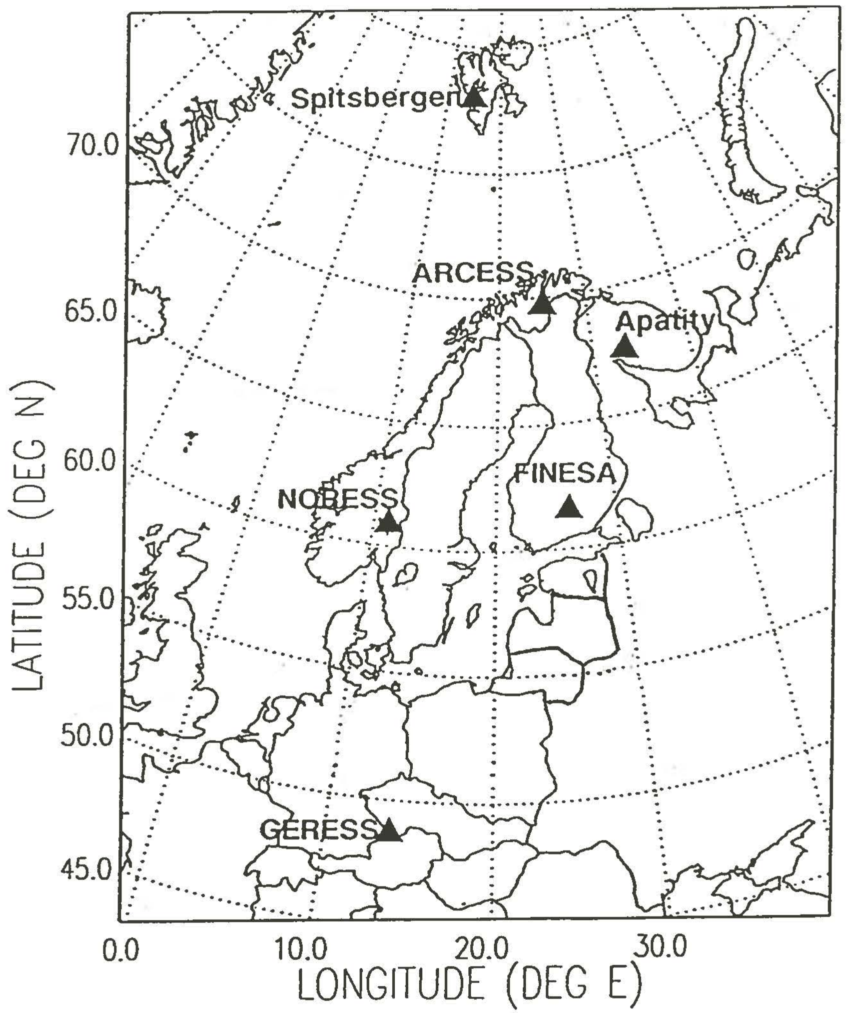
Each array produces an extremely large volume of data. Further, these new arrays are far more sensitive than traditional seismic stations and thus detect many more signals. Consequently, the analysis task is much greater and more complex, requiring a new approach to seismic data processing, analysis and management.

The IMS is a fully automated computer hardware and software system which analyzes the data from a network of stations to locate and identify detected seismic events. The system has several elements distributed between the NORSAR Data Analysis Center, and the ARPA Center for Seismic Studies near Washington, D.C. Although the two analysis centers are separated by the Atlantic Ocean, their computers are connected by a direct high-speed link, and they are in constant communication across this link as if they were in the same location.

In this way, each of the two centers has identical capabilities to analyze the recorded data and access the data base for research purposes. Through international seismic data exchange, the data and results of this research are made available also to scientists from other countries.

Besides NORESS and ARCESS, the network of regional arrays in Europe currently includes arrays in Germany (GERESS), Finland (FINESA), Russia (Apatity) and on the island of Spitsbergen. Through cooperative agreements with the host countries where appropriate, data from all these arrays are transmitted to Kjeller via dedicated high-speed data links, and are thus available to the IMS processing.

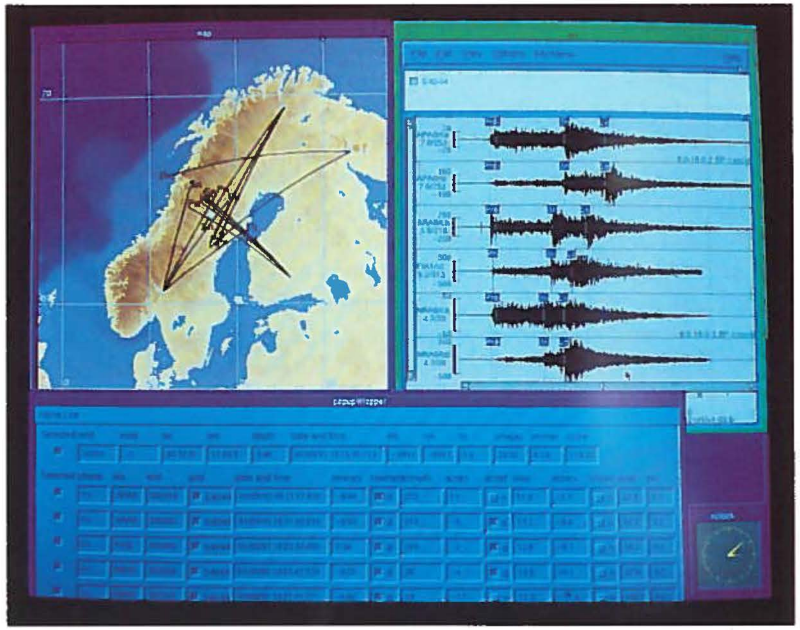
Regional Seismic Array Network



The network of high-quality regional arrays in northern and central Europe is shown on this figure. Array data centers in Kjeller, Bochum, Helsinki and Apatity are connected via high-speed data links, giving all participants access to all of the data and to the results of the IMS processing carried out at NORSAR.

Automatic Signal Processing

The interpretation of the seismic data by the automated processing in IMS is presented to a seismic analyst for review and validation in the form of standard displays for consistency of event review. The signals are presented as filtered beams with the detections marked and labeled with their seismic interpretation (i.e., Pn, Lg, etc.). A map showing the seismic location and the error bounds of the automated event solution is provided with an estimate of the direction of arrival for each signal from this event.



Interactive Event Analysis

After the automatic IMS solution has been produced, the analyst can review this solution in detail and change any aspect by manipulating the waveform and map displays. All the results, including changes made by the analyst, are automatically updated into a data base and monitored to make improvements to the automated and interactive processing as experience grows and new research results become available.

Fusion with Other Information

In addition to access to all the results of the automated processing, IMS incorporates the ability for an analyst to view high-quality satellite images from the SPOT Image Corporation. In combination with the raw and processed data, the analyst is able to review satellite imagery around the event locations. The 20 by 20 km area shown is in Estonia, and the small circle encloses a quarry which is the probable source of a detected seismic event. The ellipse marks the 95 per cent confidence limits for the location based on seismic data alone.

The Data Centers

The high-speed transatlantic link enables coordination of the data analysis and interpretation between the data centers in Norway and the United States. Pictures from these two centers are shown below.

ARPA
Center for Seismic Studies

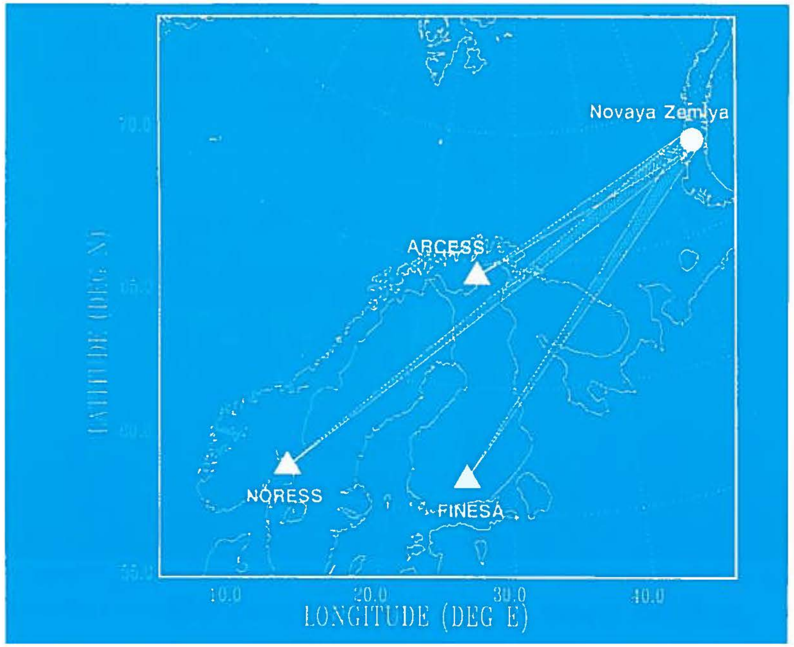
NORSAR
Data Processing Center

Continuous Threshold Monitoring

Continuous threshold monitoring is a method for monitoring a specific geographical area continuously in time. The resources of a network of arrays and single stations are combined to "focus" on a target site, so as to continuously assess the upper magnitude limit on possible seismic events at the site. The monitoring capability is optimized by fine tuning the frequency filters and array beams to known characteristics from previously recorded events at or near the site.

This technique is being experimentally applied at NORSAR to monitor several areas of interest, including the Novaya Zemlya nuclear test site. These experiments have demonstrated that the three regional arrays NORESS, ARCESS and FINESA can provide reliable monitoring down to very low magnitudes (m_b below 3.0), even though they are all more than 1000 km away from the test site. In a future verification environment, the threshold monitoring technique is expected to provide a valuable supplement to the IMS processing.

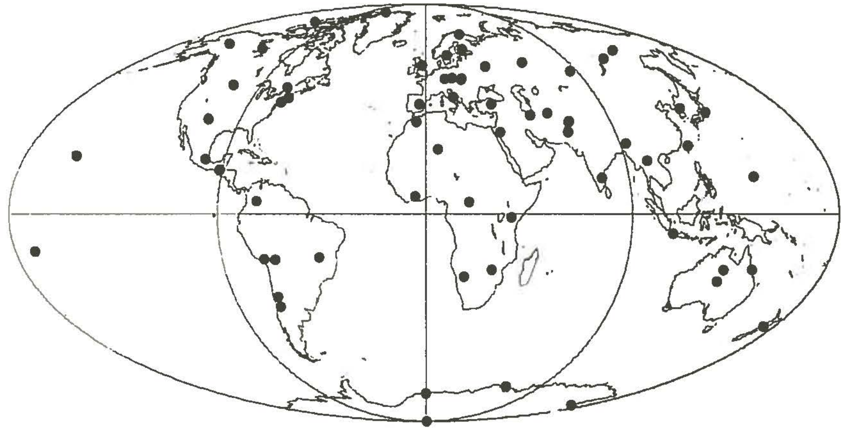
Threshold Monitoring of Novaya Zemlya



International Cooperation

Cooperative international efforts in the exchange and analysis of seismic data will form a vital part of CTBT verification. A key contribution in this regard has been the work of the Group of Scientific Experts (GSE) of the Conference on Disarmament. Since 1976, the GSE has conducted extensive studies and data exchange experiments regarding international cooperative measures to detect and identify seismic events.

Norway has consistently supported these efforts, both through active participation in the work of the Conference on the nuclear test ban issue and through significant contributions by Norwegian scientists to the GSE. Already in 1986, Norway formally proposed to the Conference on Disarmament that the global seismological network envisaged by the GSE should incorporate the establishment of small-aperture seismic arrays conforming to the NORESS concept earlier described.



The Group of Scientific Experts (GSE) established by the Conference on Disarmament has proposed a global seismic network to assist in verifying a comprehensive test ban treaty. The stations in this network are shown on the figure.

The GSETT-2 Experiment

In 1992, the GSE completed its second large-scale international seismic data exchange experiment (GSETT-2). Among the most remarkable results was the excellent detection performance demonstrated by the arrays participating in the experiment. The GSE concluded that arrays should be the backbone of any future monitoring system, and recommended that a future global network of stations should include arrays to the greatest degree practicable.

Future Perspectives

A global seismological network would represent the cornerstone of a verification system for a comprehensive nuclear test ban. Great importance should therefore be attached to the continued efforts of the Group of Scientific Experts to develop a global system for the international exchange of seismic data, and the most recent technological developments should be utilized for this purpose.

In order to ensure adherence to such a future treaty, a global system will have to include high-quality seismic stations which are capable of detecting and identifying very small events. The regional arrays based upon the NORESS design represent some of the most significant recent advances in this regard, and should be taken into account when developing standards for the global network.

The Norwegian Government has made a commitment to make the seismic installations in Norway available for the global seismological network. Norway will furthermore continue to support the Group of Scientific Experts in its work toward developing reliable verification measures for a comprehensive nuclear test ban treaty.

NORSAR
P.O. Box 51, N-2007 Kjeller
Norway

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