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7.1 Report from the symposium on "Regional Seismic Arrays and Nuclear Test Ban Verification" in Oslo, Norway, 14–17 February 1990

During 14–17 February 1990 NORSAR hosted an international symposium entitled "Regional Seismic Arrays and Nuclear Test Ban Verification". The symposium was attended by 76 scientists and representatives from 21 countries, including a large number of seismologists participating in the work of the Conference on Disarmament's Group of Scientific Experts (GSE) in Geneva.

The purpose of the symposium was to assess the state-of-the-art of research on regional seismic arrays and associated topics. In particular, the symposium focused upon the advanced regional arrays NORESS and ARCESS in Norway and their associated data processing facilities, in the light of the potential of such arrays to provide a much improved monitoring capability for a future comprehensive nuclear test ban treaty. During a three-day scientific symposium, a number of presentations were given on topics relevant to this issue. A special session was devoted to summarizing the experience and discussing further plans for the on-going international GSE experiment (GSETT-2).

In this paper, we give a brief review of some of the results presented during the scientific symposium. A list of all the presentations is provided in an appendix, and the numbers in brackets refer to this list. The majority of the papers have been submitted for publication to the *Bulletin of the Seismological Society of America*, and will be published in a Special Issue of the *Bulletin*, scheduled to appear in the fall of 1990.

Development of regional arrays

Reviews of recent developments with regard to regional seismic arrays are presented for NORESS and ARCESS in Norway [1], GERESS in the Federal Republic of Germany [2] and FINESA in Finland [3]. Paper [1] summarizes the design considerations leading to the establishment of the first regional array, NORESS, and describes how the success of this new array concept motivated the deployment of additional arrays of this type. The paper documents the basic signal processing techniques used in real-time data analysis for regional arrays, and demonstrates the excellent detection performance of such arrays at regional distances (less than 2000 km). It is shown that NORESS and ARCESS are capable of detecting seismic events of magnitude 2.5 with 90 per cent probability, if these events occur within 1000 km distance, whereas global teleseismic networks have much higher event detection thresholds. The FINESA array is also documented to have an excellent performance [3], and together, these three arrays are capable of locating weak seismic events in Fennoscandia very accurately (typically to within 10–20 km). The GERESS array currently under development shows many of the same excellent features [2], and will contribute further to an excellent regional coverage of large parts of Northern Europe.

Processing of data from a network of regional arrays

Recent technological advances have allowed very sophisticated processing techniques to be applied in detecting, locating and identifying seismic events using a network of seismic arrays and single stations, and this is highlighted by the development of the Intelligent Monitoring System (IMS) [4],[5]. Two of the goals for this system are (1) to demonstrate the monitoring performance and capability of the system for small events at regional distances and (2) to explore the promise of an expert-systems approach for providing improved monitoring performance as experience accumulates. The first operational version, described in [4], processes data from NORESS and ARCESS, whereas later versions will be expanded to networks including both arrays and single stations. The IMS is ambitious in exploring and integrating many new computer technologies, and the validity of the concept is documented in an evaluation of its initial operational performance [5].

Signal analysis methods

A number of presentations addressed methods for processing seismic signals recorded by arrays as well as three-component stations. It was demonstrated that both types of stations can provide information very useful in phase identification, azimuth estimation and estimating the apparent velocity of detected phases. From theoretical considerations as well as from experimental comparison [12],[26],[14] arrays are shown to be superior in this regard at low signal-to-noise ratios, although the precision e.g. of azimuth estimates is influenced by a number of factors, including phase type, frequency of the signal and systematic bias caused by earth heterogeneities [14],[18], [26]. A very promising approach, discussed in [17] is that of joint analysis of 3-component and array data.

Signal detection methods are discussed in several papers. In [11], a system for on-line detection and signal analysis is presented as applied to a Soviet 3-component station in Kazakhstan. In [13], a detection technique is described using NORESS array and 3-component data. A statistical approach, using adaptive techniques, to detection processing and estimation is presented in [7] for array data and [15] for 3-component data. A new approach to obtain precise relative location estimates of seismic events, using high frequency recordings, is presented in [25].

Source identification

Traditionally, seismic discrimination research has focused on distinguishing between earthquakes and underground nuclear explosions. Under a Comprehensive Test Ban Treaty, emphasis will be on detecting and identifying *weak* seismic events, and a third category, large chemical explosions for industrial purposes (e.g. mining work) will become important to consider. In [10], a very promising method is applied to NORESS data to discriminate between earthquakes and ripple-fired quarry blasts (mining events consisting of several explosions closely grouped in space and time). Using spectral characteristics of the signals, an "automatic" discriminant is proposed computing the likelihood that ripple firing occurred in each given case.

In [8], a novel approach making use of artificial neural networks is used to develop a classification procedure between earthquakes and mining explosions. Also in this approach, the spectral characteristics of the signals form the basis for the discriminants. The neural network appears to improve in particular the classification of outliers in the population, and reduce the number of uncertain events. Application of neural networks in improving seismic processing performance is also addressed in [9].

Of considerable interest for source identification is also the method proposed in [16], applying transfer functions to transform e.g. between recordings of presumed single explosions and ripple-fired explosions, and also between recordings at different NORESS sensors for a given event. This gives promise to improve the coherence of seismic phases recorded at an array, with ensuing implications for improved source parameter estimation. In [6], a case-based reasoning approach to event identification is discussed, and a waveform envelope matching technique is applied to a set of Western Norway earthquakes and explosions.

Detection thresholds and in-country networks

While regional arrays were originally designed to enhance the capabilities for detecting and characterizing weak seismic events at regional distances, they have also been found very effective in the teleseismic distance range. As an example, published yields of Soviet underground nuclear explosions at Semipalatinsk have been used to evaluate the NORESS detection threshold, in terms of explosive yield for events at this test site [21]. The threshold for detection at NORESS is estimated to be as low as 0.1 kt, assuming full coupling and normal noise conditions. It is pointed out that NORESS has particularly favorable conditions for detecting small events from this test site, and that the seismic identification threshold necessarily will be higher than the detection threshold.

Data from new Global Seismic Network stations in the Soviet Union, installed as a cooperative project between American and Soviet scientists, have been applied in several studies to address problems relevant to an in-country monitoring network. Seismic noise levels at these stations are analyzed in [19], and found to be higher than at NORESS in the band 1-20 Hz, with maximum difference ranging from 7 to 25 dB, depending on the station. However, significant noise reduction can be achieved by borehole deployment.

Using data from stations in the USSR, the frequency-dependent attenuation of regional seismic phases has been studied in [22]. Attenuation characteristics are found to be similar to those observed in Scandinavia, but with an absolute Pn amplitude almost a factor of 2 higher in eastern Kazakhstan for a fixed Lg magnitude.

Recordings of Semipalatinsk nuclear explosions at the new Global Seismic Network stations in the Soviet Union, together with data from stations in China have been analyzed in [20] and it is shown that RMS Lg can be measured at widely separated stations with a remarkable degree of consistency. The standard deviation of the differences between pairs of stations is as low as 0.03–0.04 in logarithmic units, and reliable measurements may be made at magnitude (m_b) down to about 4.0 for stations situated about 1500 km away from Semipalatinsk. The importance of this observation in terms of supplying yield estimates for nuclear explosions down to and even below one kiloton is pointed out.

Earth structure, wave propagation, scattering

Several of the papers were devoted to studies of general problems in seismology and geophysics, in areas relevant to the seismic monitoring issue. The structure of the crust and upper mantle in parts of Northern Eurasia is addressed in papers [23], [24], [27] and [29], with the three latter papers specifically making use of regional array data. Seismic wave propagation and scattering are addressed in a number of papers, e.g. [13], [26], [28], [29], [30].

Conclusion

The Oslo symposium demonstrated the considerable progress in the field of seismic monitoring during recent years. It particularly highlighted the technological advances in seismic instrumentation, data communication and computer processing, as exemplified by the development of advanced regional seismic arrays with very sophisticated automatic and interactive signal processing facilities. The presentations at the scientific symposium show that these technological advances are accompanied by considerable scientific progress, although much work remains in order to fully exploit the potential offered by regional arrays in a seismic monitoring context.

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Appendix

List of scientific presentations given during the 1990 Oslo Symposium on Regional Seismic Arrays and Nuclear Test Ban Verification

References

[1] Svein Mykkeltveit[1], Frode Ringdal[1] and Ralph W. Alewine[2] — [1] NORSAR, Norway, and [2] DARPA, USA: "Application of Regional Arrays in Seismic Verification Research"

[2] Hans Peter Harjes — Ruhr Univ., Fed. Rep. of Germany: "Design and Siting of a New Regional Array in Central Europe"

[3] Marja Uski — University of Helsinki, Finland: "The Upgraded FINESA Array and Experiences of Data Analysis"

[4] Thomas C. Bache[1], James Wang[1], Robert M. Fung[2], Cris Kobryn[1] and Jeffrey Given[1] — [1] Science Applications International Corp., USA, and [2] Advanced Decision Systems, USA: "The Intelligent Monitoring System"

[5] Steven Bratt, Henry Swanger, Richard Stead and Floriana Ryall — Science Applications International Corp., USA: "Results from the Intelligent Monitoring System"

[6] Douglas Baumgardt and Gregory Young — ENSCO, Inc., USA: "Regional Seismic Waveform Patterns and Case-based Event Identification using Regional Arrays"

[7] A. Kushnir, V. Laphsin, V. Pinsky and V. Pisarenko — Inst. of Physics of the Earth, USSR: "Statistical Procedures for Seismic Signal Detection and Estimation by using Small Array Data"

[8] Paul Dysart[1] and Jay Pulli[2] — [1] Science Applications International Corp., USA, and [2] Radix Systems, Inc., USA: "Regional Seismic Event Classification at the NORESS Array: Seismological Measurements and the Use of Trained Neural Networks"

[9] Kenneth Anderson — BBN, USA: "Automatic Improvement of Seismic Array Performance"

[10] Michael J. Hedlin, J. Bernard Minster and John A. Orcutt — Scripps Inst. of Oceanography, UCSD, USA: "An 'Automatic' Means to Discriminate between Earthquakes and Quarry Blasts"

[11] O.K. Kedrov and V.M. Ovtchinnikov — Inst. of Earth Physics, USSR: "An On-Line Analysis System for Three-Component Seismic Data: Method and Preliminary Results"

[12] David B. Harris — Lawrence Livermore National Laboratory, USA: "A Comparison of the Direction Estimation Performance of High-Frequency Seismic Arrays and Three-Component Stations"

[13] B.O. Ruud, E.S. Husebye and S.C. Bannister — University of Oslo, Norway: " NORESS Recording — Joint 3C and Array Analysis"

[14] Anne Suteau-Henson — Science Applications International Corp., USA: "Estimating Azimuth and Slowness from Three-Component and Array Stations"

[15] A. Kushnir, V. Pinsky, V. Pisarenko and I. Savin — Institute of Physics of the Earth, USSR: "Wavelet Decomposition and Parameter Estimation Using 3-Component Seismograms"

[16] Zoltan A. Der[1] and Robert H. Shumway[2] — [1] ENSCO, Inc., USA, and [2] University of California at Davis, USA: "Coherent Array Processing of Regional Seismic Data for Ripple Fire Patterns, Source Mechanisms and Source Azimuths"

[17] D.C. Jepsen and B.L.N. Kennett — Australian National University, Canberra, Australia: "Three-component Array Analysis of Regional Seismograms"

[18] Dorthe Bame, Marianne C. Walck and Kathie L. Hiebert-Dodd — Sandia National Laboratory: "Azimuth Estimation Capabilities of the NORESS Regional Seismic Array"

[19] Holly K. Given — Scripps Inst. of Oceanography, UCSD, USA: "Broadband Seismic Noise and Detection Experiments at IRIS/IDA Stations in the USSR"

[20] Roger A. Hansen[1], Frode Ringdal[1] and Paul G. Richards[2] — [1] NORSAR, Norway, and [2] Lamont-Doherty Geological Observatory, USA: "The Stability of RMS Lg Measurements, and their Potential for Accurate Estimation of the Yields of Soviet Underground Nuclear Explosions"

[21] Frode Ringdal — NORSAR, Norway: "Teleseismic Event Detection using the Small-Aperture NORESS and ARCESS Arrays"

[22] Thomas Sereno — Science Applications International Corp., USA: "Frequency-Dependent Attenuation in Eastern Kazakhstan and Implications for Seismic Detection Thresholds in the Soviet Union"

[23] A. Egorkin — International Inst. of Earthquake Prediction, USSR: "New Methods of Seismic Surface Wave Data Processing and its Application for the Study of the North Eurasian Shelf Structure"

[24] Vladimir Ryaboy — Science Applications International Corp., USA: "Upper Mantle Structure along a Profile from Oslo (NORESS) to Helsinki to Leningrad, based on Explosion Seismology"

[25] Hans Israelsson — Science Applications International Corp., USA: "Studies Using Seismic High Frequency Data"

[26] Erik Ødegaard[1], Durk Doornbos[1] and Tormod Kværna[2] — [1] University of Oslo, Norway, and [2] NORSAR, Norway: "Topographic Effects on Arrays and Three-Component Stations"

[27] Kristin Vogfjord and Charles Langston — Penn State Univ., USA: "Analysis of Regional Events Recorded at NORESS"

[28] I. Gupta, C.S. Lynnes and R.A. Wagner — Teledyne Geotech, USA: "F-K Analysis of NORESS Array and Single-Station Data to Identify Sources of Near-Receiver and Near-Source Scattering"

[29] Douglas Baumgardt — ENSCO, Inc., USA: "Investigation of Teleseismic Lg Blockage and Scattering using the NORESS and ARCESS Regional Arrays"

[30] Anton Dainty and M. Nafi Toksoz — Earth Resources Lab., MIT, USA: "Array Analysis of Seismic Scattering"