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REPORT OF THE AD HOC GROUP OF SCIENTIFIC EXPERTS TO THE CONFERENCE ON DISARMAMENT ON THE GSETT-3 EXPERIMENT AND ITS RELEVANCE TO THE SEISMIC COMPONENT OF THE COMPREHENSIVE NUCLEAR TEST-BAN TREATY INTERNATIONAL MONITORING SYSTEM

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Executive Summary

The Ad Hoc Group of Scientific Experts (GSE) has for the past several years developed an experimental global seismic monitoring system intended to test concepts for possible use in a future CTBT International Monitoring System (IMS). These activities, known as the GSE Third Technical Test (GSETT-3), have built upon the previous experience of the GSE and have involved the participation of 60 countries.

The GSETT-3 experiment began full-scale operations on 1 January 1995 and is continuing. This report gives a comprehensive overview of the results and conclusions from a year and a half of GSETT-3 experience. The report also includes specific recommendations resulting from the experiments. These recommendations could be used to facilitate a smooth and orderly transition from GSETT-3 to the envisaged IMS.

Overall Concepts

The GSETT-3 experience has served to validate the viability and effectiveness of the concepts for an International Seismic Monitoring System originally specified in CD/1254. These concepts include: a single centralized International Data Center (IDC); a specifically designed high-quality seismographic network consisting of about 50 primary stations and 100-150 auxiliary stations; National Data Centers (NDCs) in participating countries; and a modern communications system to support data exchange among these elements.

Although the emphasis during GSETT-3 has been on seismic monitoring, practical experiments have demonstrated that the system design is flexible enough to incorporate the collection, processing, archiving and distribution of data from other monitoring technologies. Thus, the GSETT-3 system can provide the infrastructure needed for radionuclide, hydroacoustic and infrasound monitoring as envisaged for the IMS. In fact, these concepts are reflected in the proposed CTBT treaty text (CD/NTB/WP.330/Rev.1).

Station network and communications

To conduct the GSETT-3 experiment, participating countries have established and operated both primary and auxiliary stations. Altogether, a total of 43 primary and 90 auxiliary stations have participated in the GSETT-3 network. The primary and auxiliary seismograph networks described in the proposed treaty text have evolved from partial networks established for the GSETT-3 experiment and on the basis of deliberations by the Ad Hoc Committee on a Nuclear Test Ban. Not all of the stations in the GSETT-3 network are included in the proposed IMS. However, at the present time, the operational GSETT-3 network includes 32 of the 50 proposed IMS primary stations and 38 of the 120 proposed IMS auxiliary stations.

The Ad Hoc Group has taken two steps toward the orderly transition from the GSETT-3 network to the proposed IMS seismic network: (1) the removal from participation of some GSETT-3 stations that are not part of the proposed IMS; and (2) continuing attempts to encourage additional countries that have stations in the proposed IMS to join the GSETT-3 experiment (CD/1398). The participation in GSETT-3 of additional stations not envisaged for the IMS has been useful in providing temporary substitutes for IMS stations not yet available and has been essential for providing a realistic data processing load required for the development of the IDC.

The Ad Hoc Group developed technical specifications for IMS seismograph stations and tested the performance of these specifications in GSETT-3. The Group has concluded that careful attention should be given to both equipment technical specifications and to station siting considerations.

GSETT-3 has provided extensive experience in setting up and maintaining the types of communications links required for the transmission of data. These communications involve a variety of dedicated satellite, dedicated land-line circuits, microwave and radio relay links and were established on a bilateral, individual basis between the NDCs and the IDC. However, the communications arrangements for GSETT-3 were not planned and installed in an optimum manner from a cost or efficiency standpoint.

During GSETT-3, data from auxiliary seismic stations were collected using two types of communications: on-demand (dial-up) telephone lines and requests forwarded through the INTERNET computer network. Although the GSETT-3 benefited from the use of the INTERNET in terms of both cost and effectiveness on an experimental basis, there could be some concern about its use in the future treaty because of security, timeliness and reliability considerations in an operational situation.

National Data Centers (NDCs)

During GSETT-3, the National Data Centers have played a critical role in the operation and maintenance of reliable stations and communication links, and formed an effective interface between the GSETT-3 IDC and participating States through which data and products could be accessed and evaluated.

In addition to their main functions concerned with providing data from seismograph stations, NDCs have had an active role in the evaluation of the results of GSETT-3. Many NDCs have provided supplementary information on seismic events based on analysing data from national or regional networks. Such national contributions could be useful in the IMS, for example, in contributing to the calibration of the IMS network.

International Data Center (IDC)

An experimental International Data Center was established for the GSETT-3 following a lengthy and complex preparation. The GSETT-3 IDC has been in continuous operation since 1 January 1995, with only minor interruptions, acting as a data collection, processing and distribution facility for the entire GSETT-3 network. The GSETT-3 IDC performance has improved and expanded significantly during the experiment. With only a few exceptions, the major technical problems have been solved.

GSETT-3 has demonstrated that a single IDC of the structure and size established for the experiment can successfully carry out the tasks envisaged under the IMS, including:

- acquire and archive the volume of seismic data that is anticipated for the IMS under a CTBT;
- routinely analyze this large volume of data in a timely manner;
- produce and distribute defined standard products that are useful for monitoring and system evaluation.

Many of the functions envisaged for the IMS/IDC have already been implemented in the GSETT-3 IDC. However, further improvements are needed, especially in the areas of improved redundancy and data security.

Seismological Performance

The seismological performance during GSETT-3 has shown steady improvement as the GSETT-3 has proceeded. Due to limited resources during GSETT-3, little effort has been devoted to new seismological concepts. Priority has been given to the production of a comprehensive daily bulletin using traditional seismological methods. The results of the performance evaluation have been documented in a comprehensive report (GSE/CRP/262) which also contains specific areas in which additional work is needed. New software designed for improving the automation and efficiency for signal detection and phase association have made significant contributions to improved performance; however, improvements in other procedures such as depth and magnitude determination, are still required.

Although a high degree of effective automatic data processing is desirable, it is recognized that review and revision (if necessary) by human analysts will always be required. Efforts should continue to improve and refine the automatic procedures and to reduce the need for analyst intervention in these procedures and in the correction of their results.

Both the detection and location capabilities of the GSETT-3 network are presently very heterogeneous. Network simulation has shown that these capabilities will be more homogeneous as the network approaches that of the IMS. Network tuning and calibration will, however, be required to achieve the detection and location capabilities expected for an operational IMS.

Documentation

The GSE has developed an extensive set of documentation for GSETT-3. This documentation includes a detailed description of the plan for GSETT-3, detailed instructions for all aspects of the GSETT-3 operations, information on the facilities which are part of GSETT-3, and the procedures and results of the evaluation of the experiment. This documentation, comprising about 1,000 printed pages, is available in both hard copy and in electronic form. However, due to limited resources, the documentation is not yet complete. Also, there is a need to develop additional documentation that would be required for the future IMS operational manuals.

The GSETT-3 experience has demonstrated that such detailed documentation is essential. The electronic version of the documentation has proved especially useful, making distribution easy and making it possible to keep the information up-to-date. Major portions of the documentation have direct relevance to the documentation that will be required in the envisioned IMS operational manuals.

Recommendations on Transition to the IMS

Based on the extensive experience gained in carrying out GSETT-3 a number of results are emerging which could prove to be useful in establishing and operating the future IMS. These recommendations could provide guidance to achieve a smooth transition from GSETT-3 to the IMS.

Recommended technical changes

- There should be an orderly transition from the GSETT-3 to the IMS network, with the inclusion of stations envisaged for the IMS as they become available.
- There should be a continuous assessment of the contributions of primary and auxiliary stations and recommendations for replacements should be made as appropriate.
- There should be a complete review of the technical specifications of IMS seismograph stations drawing on the GSETT-3 experience.
- Data authentication procedures should be evaluated and implemented.
- The technical characteristics and reliability of stations and communications should be evaluated and upgraded as necessary.
- An IMS data communications concept, more cost-effective than that used in GSETT-3, needs to be established.
- More redundancy and security at all levels of the system (stations, communications, NDCs, and the IMS/IDC) is needed.
- IDC products with emphasis on functionality, reliability, and user-friendliness need to be developed.

- The IMS/IDC should develop improved testing procedures for data processing software.

- Data from other monitoring technologies should continue to be integrated into the GSETT-3 IDC system.

Recommended improvements to seismological procedures

- There should be continued tuning of the automatic data processing at the IMS/IDC including detection, phase identification, and phase association.

- Improved automatic consistency checks to reduce the number of false events are needed.

- Calibration of the network event location procedures, in accordance with the plan outlined by the GSE, should be carried out.

- Improvements are needed in the calculation of event locations and the specification of the associated uncertainty.

- Improved routines for data retrieval from auxiliary stations are needed.

- The methods for estimating seismic magnitudes (including Ms) should be reviewed and improved.

- Existing event depth estimation methods need to be reviewed and improved; alternative methods should be considered.

- Methods to calculate source characterization parameters should be tested and implemented.

Recommended organisational provisions

- GSETT-3 documentation should be developed in a form that is appropriate to serve as a complete and up-to-date operations manuals for the IMS and reference manuals for quality assurance and training purposes. The new documentation should be made available electronically, as in GSETT-3.

- The IMS should develop and implement a quality assurance plan.

- A plan for establishing an operational IMS/IDC will be required and should draw on GSETT-3 experience.

- The roles of the NDCs with respect to the IMS/IDC need to be more fully defined including in areas such as: timely and complete data accessibility, data transfer, station monitoring and maintenance, and quality assurance.

- Periodic evaluation of IMS/IDC scientific and technical procedures and products should be carried out by an independent, external panel of qualified specialists.

- A plan is needed for the training of future IMS/IDC and, as requested, NDC personnel.

- Regional workshops and other activities needed to coordinate and promote IMS activities should be pursued.

1. Introduction

The Conference on Disarmament's Ad Hoc Group of Scientific Experts (GSE) has for the past several years developed an experimental global seismic monitoring system intended to test concepts for possible use in a future CTBT International Monitoring System (IMS). These activities have culminated in the GSE Third Technical Test (GSETT-3), and build upon many years of experience in seismic monitoring research, including two previous global technical tests carried out by the GSE in 1984 and 1991.

The GSETT-3 system began full-scale experimental operation on 1 January 1995. This report gives a comprehensive overview of the current GSETT-3 results and experience, building upon a year and a half of successful operation. It also includes specific recommendations resulting from the experiment. These recommendations could be used to facilitate a smooth and orderly transition from GSETT-3 to the envisaged IMS.

The primary GSETT-3 objectives have been to:

- develop and test new concepts in an experimental International Seismic Monitoring System, building upon previous experience;
- provide a practical basis upon which to furnish the Conference on Disarmament with timely technical information;
- develop an experimental system that can evolve and adapt to support future requirements.

To meet these objectives, the GSE has, during GSETT-3, developed and tested an experimental seismic monitoring system comprising three main components:

- A network of highly sensitive primary and auxiliary seismic stations distributed around the globe, and operated according to internationally agreed rules;
- National Data Centers (NDCs) in participating countries, responsible for operating the stations and making the data expeditiously available to the international system;
- An Experimental International Data Center (EIDC) responsible for collecting, processing and archiving the recorded data and providing the participants with data and analysis results on a timely basis.

An integral part of GSETT-3 has been the use and evaluation of communication links connecting the EIDC with the national facilities. This has comprised both high-speed continuous links and on-demand links as required.

GSETT-3 is an unprecedented global effort to conduct an operationally realistic test of key features of a global seismic monitoring system, including:

- rapid acquisition and processing of data from a global network of stations at a central processing facility;
- prompt and convenient provision of reliable data to all participating States;
- as much automation as possible in the collection, processing and distribution of data;
- permanent archive of all data collected or generated by the system;
- security and quality control;
- an architecture which will permit modifications and improvements as they are judged desirable.

While the emphasis during GSETT-3 has been on seismic monitoring, the system design has proved flexible enough to incorporate the collection, archiving and distribution of data from non-seismic techniques, for example, radioactivity, hydroacoustics and infrasound.

2. Seismograph networks

The primary and auxiliary seismograph networks described in the proposed treaty text (CD/NTB/WP.330/Rev.1) have evolved from partial networks established for the GSETT-3 experiment, and on the basis of deliberations by the Ad Hoc Committee on Nuclear Test Ban. The purpose of this section is to describe the present status of the GSETT-3 network; to summarize the types of stations and instrumentation that are found in the network; to describe the performance of different station types and the effects of site conditions; and to compare the GSETT-3 network with the proposed IMS network. This section concludes with recommendations that may be useful in completing the seismograph network component of the proposed IMS.

2.1 The GSETT-3 Primary and Auxiliary Seismograph Networks and their Contributions to the IMS Networks

The seismograph stations in the GSETT-3 primary and auxiliary seismograph networks are listed in Tables 1 and 2 in Appendix A, respectively. Tables 1a and 2a list the IMS primary and auxiliary stations, with an indication of which of these stations are participating in GSETT-3 as of August 1996; Tables 1b and 2b list the additional stations that are participating in GSETT-3, but are not part of the IMS networks.

Altogether 43 primary and 90 auxiliary seismic stations in 49 countries have so far participated in the GSETT-3 experiment. In addition, several countries have contributed in other ways, such as providing supplementary data from their national networks, so that altogether 60 countries have participated in GSETT-3.

Figure 2.1 shows a map of the IMS primary seismograph network with symbols that distinguish seismic arrays and three-component stations, and shows which stations are currently operating as part of GSETT-3. There are 32 of the 50 IMS primary stations currently participating in GSETT-3.

Figure 2.2 shows a map of the IMS auxiliary seismograph network with symbols that distinguish three-component stations and arrays, and showing which stations are currently operating as part of GSETT-3. There are 38 of the 120 auxiliary stations currently participating in GSETT-3. Although GSETT-3 has had 90 auxiliary stations participating, the reasons for the relatively small fraction of IMS auxiliary stations currently participating in GSETT-3 are twofold: (1) GSETT-3 had high concentrations (more than necessary) of auxiliary stations in North America, Europe and Australia simply because they were available and useful for gaining practical experience; and (2) the IMS Experts have significantly reduced the numbers of auxiliary stations in these regions and attempted to produce a reasonably uniform coverage in other continental areas, regions of the globe where communications, in particular, have been difficult and few stations have been able to participate.

The Ad Hoc Group has taken two steps toward the orderly transition from the GSETT-3 network to the proposed IMS network: (1) the removal from participation of GSETT-3 stations that are not part of the proposed IMS; and (2) continuing attempts to encourage additional countries that have stations in the IMS to join the GSETT-3 experiment (CD/1398).

2.2 Station Types, Instrumentation and Data Availability Standards

Sixteen of the primary stations currently operational in GSETT-3 are array stations; 14 of these are included in the IMS primary network; and an additional 17 stations to be added to the IMS primary network (Table 1a) are planned to be array stations. The existing array stations are highly variable in size and shape, ranging through large-aperture teleseismic arrays, to medium- aperture arrays, to small-aperture arrays, each one with a different geometrical configuration and instrumentation. The arrays make the dominant contribution to global detection capability, as noted below, and there is no necessity to impose a particular design configuration on IMS arrays, because each is designed to suit the particular local conditions and the distribution of seismic events it is intended to detect.

The three-component stations in the network are more standardized, in the sense that most of them contain three orthogonal broadband seismometers at a single site; however there is a wide range of instrumentation in the seismometers and electronics in these stations.

The Ad Hoc Group has previously developed technical specifications for IMS seismograph stations (CD/1211), and, in its forty-fourth session, began to consider revisions to these specifications based on GSETT-3 experience. It was found during GSETT-3, however, that stations not meeting the stringent technical specifications made significant contributions to the experiment. The Group continues to believe that careful attention should be given to both equipment technical specifications and to siting considerations.

A careful accounting has been performed during GSETT-3 of each primary station's data availability at the EIDC, and attempts are made by both the NDCs and the EIDC to establish the reasons for loss of data. The Ad Hoc Group has recommended that data availability at the EIDC of 99% would be a reasonable target (see GSE/CRP/243); however, it will be important to establish if this target is cost effective and this is a task for the future. On many of the station-to-EIDC circuits during GSETT-3 the communications have been highly reliable, and it is assumed that reliable communications can be designed for the IMS (see below). Many of the causes of lost data were problems at the stations: power interruptions, lightning strikes, failures in equipment, etc. Guaranteeing a 99% data availability will require a significant hardening of the stations against these problems, equipment with low power consumption, a ready supply of spare components, and technical staff available to make repair trips to remote stations at short notice, all of which will affect station costs.

2.3 Station Performance and Network Modifications

During GSETT-3, statistics have been kept on the numbers of seismic event locations to which each station contributes. To some degree this is influenced by the rates of earthquakes and other seismic events, e.g., blasting, within detection range of the stations, and by the degree of tuning that automatic detectors have undergone, but the most important factors are the station type (array or three-component) and ambient background noise.

The best eight GSETT-3 primary stations, in terms of numbers of events recorded, are array stations, all of which have been carefully sited in seismically quiet locations. Some of the GSETT- 3 primary stations have been relatively ineffective, due mainly to high background noise levels. During GSETT-3 no decisions have been made to remove ineffective stations from participation unless there were serious communications problems causing the non-reception of data. Under the IMS, however, the quality of the station contributions will be under constant scrutiny, and there will be opportunities to propose modifications to the network.

2.4 Data Authentication

The Ad Hoc Group has recommended (CD/1185) that the data collected from primary stations, and possibly from auxiliary stations, be authenticated in order to increase confidence that the data have not been altered. This can be accomplished by attaching a data-dependent signature to the data. A proof-of-concept field test of data authentication has been reported to the Ad Hoc Group with positive results that demonstrated the viability of the method. The system tested easily detects attempts to alter the data and attempts to gain access to the sensor and the authentication hardware. Broader international cooperation is needed to continue to test and refine these concepts. There will definitely be cost implications because of the need to add data authentication hardware to the stations.

2.5 Communications

GSETT-3 has provided an extensive experience in setting up and maintaining the types of communication links required and available for the transmission of both continuous and segmented data. The primary station data communications arrangements that are in place for GSETT-3 (see GSE/CRP/262) were not planned and installed in an optimum manner from a cost or efficiency standpoint, but rather were established mainly on a bilateral, individual basis between the NDCs and the EIDC. A wide variety of communications means were used between the stations and the NDCs and the EIDC, including dedicated satellite circuits, dedicated land-line telephone circuits, microwave and radio relay links. In many cases, several different methods were combined. Because there was no common, uniform communications plan for GSETT-3, in order to save costs, and to take advantage of existing data routing, the NDCs in Norway, the Russian Federation and the United States served as temporary communications nodes to forward data collected from other countries participating in GSETT-3.

In most cases the data flow from the station to the EIDC is via an NDC. There are, however, a number of cases in which the data flow from the station to the EIDC, via a data relay centre, without passing through the NDC. There are also cases of data flowing through relay centers from stations in countries that do not operate NDCs. There are no cases in GSETT-3 of data flowing directly from a primary station to the EIDC.

Uptime percentages of the communications links from the NDCs to the EIDC are rather high. Overall data availability at the EIDC expressed as a fraction of the total possible, covers a wide range, but exceeds 99 % over an extended period in only two cases (France, Japan).

Protocols and formats developed for GSETT-3 have been implemented in many countries. For primary data, a protocol has been developed to fill in data gaps caused by communications link or computer failures at either end, sometimes for gaps as large as several days. In general, brief interruptions in the communication links do not result in the loss of data, but do affect the timeliness of data received at the EIDC. Among the failures affecting these communication links, unreliable power is the most frequent reason.

The GSETT-3 has offered the possibility of using and testing a new development in satellite communications, the Very Small Aperture Terminal (VSAT) systems. VSAT communications is already used by several national transmission networks (Canada, US, France, Israel) and also for some regional links within the GSETT-3 network. Since the future IMS communications network is expected to transmit two or three times the amount of continuous seismic data transmitted during GSETT-3, it seems appropriate to consider use of special-purpose communications such as the VSAT. Low power rating VSAT stations now available allow the use of solar energy and consequently makes these systems attractive especially for remote and isolated sites. In general, they appear to be very cost-effective.

During GSETT-3, data from auxiliary seismograph stations were collected using two types of communications: on demand (dial-up) telephone lines and requests forwarded through the INTERNET computer network to an Automatic Data Request Manager (AutoDRM). The latter is an email-based system that produces an automatic response by the NDC computer to a received request for data or other information that is stored at the NDC. The dial-up option, used primarily to locations without an Internet connection, can be very expensive because of long-distance telephone charges. About 24 stations in 21 countries are using this technique, which has been less reliable than Internet, but it must be taken into account that most of the sites using dial-up communications are in remote locations in countries with less developed communication infrastructures. The AutoDRM systems, which differ somewhat from NDC to NDC, have shown to be quite effective, and they are cost effective given the present low cost of Internet connections. Data from more than 50 auxiliary stations have been provided to the EIDC this way. Although the GSETT-3 benefited from the use of the INTERNET in terms of both cost and effectiveness for the retrieval of auxiliary seismic data on an experimental basis, there could be some concern about its use in the future treaty because of security, timeliness and reliability considerations in an operational situation.

Costs for most of international links used to provide continuous data to the EIDC are high, averaging 100,000 USD per year, with large variations that have little relation to the distance traveled or the volume of data carried, and often reflect differences in local taxes. Concerning auxiliary data, Internet is free to the user up to now. Charges for dial-up station calls are typically several USD per minute, and with an average duration of the order of 5 minutes for each call, there are examples of costs exceeding 5,000 USD per month for some stations.

2.6 Recommendations

Based on GSETT-3 experience, the Group has the following specific recommendations with respect to the seismograph network and communications which may be useful to the Preparatory Commission:

- that the orderly transition from the GSETT-3 primary and auxiliary networks to the proposed IMS networks be continued;

- that the refinement of the technical specifications for the IMS seismograph stations, based on GSETT-3 experience, be completed;

- that the contribution of primary and auxiliary stations to the detection and location of seismic events continue to be assessed;

- that international efforts be undertaken to continue to test and refine the concepts of data authentication;

- that a comprehensive study be undertaken on a unified global communications approach for all the facilities of the proposed IMS;

- that a form of the AutoDRM system be adopted for the extraction of data from the auxiliary stations in the proposed IMS, if this is compatible with the overall global communications concept;

- that the effect of tariffs and taxes on communications costs to the proposed IMS sites be examined.

3. National Data Centres (NDCs)

National Data Centres (NDCs) serve as the interface between a participating state and the international component of the GSETT-3 system. The NDC is the gateway through which each participating state provides raw data from the stations of the seismograph network and receives processed results from the GSETT-3 EIDC.

Although most NDC's provide primary and/or auxiliary data during GSETT-3, the provision of data from either of these two sources is not a prerequisite for NDC participation in GSETT-3. The requirement for an even geographical distribution of both primary and auxiliary stations has resulted in there being no need for any stations in some countries. The existence of a NDC provides a contact point between the participating state and the international system, whether or not the NDC is providing data from seismograph stations.

Alternatively, bilateral or other arrangements were made in GSETT-3 whereby data from primary or auxiliary stations were communicated to the EIDC by some route other than through the NDC. For example, data are transmitted directly to the EIDC via a communications node which handles seismic data from several countries.

3.1 Functions of a National Data Centre (NDC)

The main responsibilities of NDCs in GSETT-3 are the maintenance of primary and auxiliary stations, the maintenance of communication links, the transmission of continuous primary data to the EIDC, the transmission of requested auxiliary waveform segments to the EIDC and reporting to the EIDC any problems affecting data quality.

Less formally, the NDCs have submitted seismic bulletins from their national networks (known as supplementary data) and provided feedback and research that have improved the performance of the GSETT-3 system and which contributed to its evaluation or assessment. This includes the provision of data relating to the properties of seismic wave propagation within the area around each seismograph station. These data are very important when calibrating the seismograph network to provide accurate locations and reliable magnitude estimates for seismic events.

In the cases where a state does not have a primary or auxiliary station within the GSETT-3 seismograph network, NDC participation is still encouraged. This participation may be through the provision of supplementary data and/or assistance with evaluation of GSETT-3 by analysing and providing feedback on EIDC products.

Other work and responsibilities within the NDC will vary depending on the requirements of the particular country. For example, these requirements may include the detailed interpretation of EIDC products, the retrieval and analysis of additional data from the EIDC, integration of data from other sources and the provision of results to other national authorities. It was agreed by the Ad Hoc Group that seismic data from the GSETT-3 experiment would be made available to other interested national parties through their respective NDC.

The facilities used by GSETT-3 NDCs vary widely according to the requirements of each state for the activities of that NDC. There are no requirements for specific equipment or staff to be employed at a GSETT-3 NDC.

3.2 Assessment of GSETT-3 NDCs

Where the NDC is responsible for maintenance of seismograph stations, this has been performed effectively as far as resources will allow. Some NDCs have been restricted in the improvements they have been able to make to their stations and communications due to lack of financial support. Details of station and communications reliability are given in Chapter 2.

There have been several occasions when the EIDC has not been notified by the NDC when a problem has arisen with a particular station. Any technical failures which affect the data being transmitted to the EIDC should be reported to the EIDC as soon as possible. There have been occasions when the EIDC has had difficulty in contacting staff at the NDCs outside normal working hours when there is a problem with a primary station.

Although 34 countries have committed themselves to contributing national network bulletins (supplementary data), there has been a very slow increase in the number of countries actually sending these data to the EIDC during GSETT-3, the latest count being 23.

Very few NDCs have provided information on local and regional travel times and amplitude attenuation curves for seismic wave propagation in the region of their stations. The EIDC is now working directly with NDCs on an individual basis to acquire this information.

The NDCs have been requested to take part in the evaluation of GSETT-3 in several ways. Some NDCs completed their own evaluation studies and presented the results in papers tabled at meetings of the Ad Hoc Group. Many of these studies showed comparisons of the locations of seismic events by the GSETT-3 system with the relevant national network and these results were very useful for the evaluation of GSETT-3. Papers were also tabled giving the results of various studies on different aspects of the GSETT-3 system and these papers were useful to the EIDC in evaluation of its processing and procedures.

3.3 Recommendations

The NDC may be regarded as the technical point of contact for any state that will interact with the International Monitoring System (IMS). It is essential that the IMS/IDC has the necessary information to be able to contact any NDC regarding technical issues connected with their station(s) outside normal working hours.

NDCs should regard the maintenance of stations and communication links as their main priority and should take all steps to ensure good data availability from both primary and auxiliary stations. Technical problems affecting these data should be reported promptly to the IMS/IDC. The link between the NDC and the IMS/IDC is an important one and should be used to ensure the IMS/IDC is kept informed of the status of stations and communications links at all times. This link should also be used for the IMS/IDC to provide feedback to the NDC on all operational matters.

In addition to their main functions concerned with providing data from seismograph stations, NDCs should take an active role in the calibration of the IMS network by providing locally dependent information and good quality supplementary data from their national network bulletins to assist in the fine tuning of the seismograph network. In particular, the NDCs should cooperate with the IMS/IDC in finding very well located events detected both by the IMS network and a national seismograph network which can be used to build up network calibration information for the IMS/IDC processing.

During the GSETT-3 experiment it has become increasingly clear that most NDCs are at present not working in an operational mode - that is they are for the most part working normal office hours and have a hardware maintenance system which does not guarantee timely repair to equipment. This mode of operation can result in large data outages due to failures within the system. If the IMS requires a high level of operational capability, provision will have to be made for equipment backup and call-out and overtime payment for NDC and station staff. This will have to be taken into account when addressing the issue of cost.

4. GSETT-3 Experimental International Data Center (EIDC)

The EIDC is the focal point of the GSETT-3 system, acting as a data collection, processing and distribution facility for the entire network. The EIDC provides products and services to all participants, and acts as storage facility for all data collected in the global system. The EIDC also oversees the overall operation of the global network of stations. In this chapter, the tasks of the EIDC are summarized in section 4.1, the performance of the EIDC is discussed in sections 4.2 to 4.5 and the most important improvements needed are given in section 4.6.

4.1 Main Functions

The main functions of the EIDC during GSETT-3 have been:

- Data acquisition. The EIDC receives raw data from the station networks and supplementary data provided by NDCs. All data have to be in accordance with the standard formats and communication protocols. The EIDC has a large number of communication links for solving this task.

- Archiving. All data received and all EIDC products are archived at the EIDC using a database management system. The volume of data archived each year is around one million Megabytes.

- Automatic signal detection. The EIDC processes the raw data and characterizes signals detected above the background noise. The quality of the raw data is checked as part of this processing and data of low quality is disregarded.

- Automatic event location and characterization. Using the detected signals, the EIDC produces lists of events. Several versions, increasingly more refined, are produced as more data are received and processed at the EIDC. Event characterization parameters are computed for each event. Uncertainties of the parameters are estimated.

- Retrieval of auxiliary data. The first version of the automatic event list is based only on primary data but later versions also use auxiliary data. Based on the automatic events, the EIDC automatically retrieves data from those auxiliary stations that are most likely to contribute significantly to the location and characterization of the events.

- Interactive analysis. Analysts review the raw data and the results of the automatic processing to improve the quality of the event list. The final product of the analysis is the Reviewed Event Bulletin, REB.

- Other EIDC products. The EIDC will begin producing executive summaries and estimates of the capability of the system, like a picture of the variation with time of the detection threshold in various regions (threshold monitoring).

- Distribution. The distribution of data and products is directed to NDCs. Other users, e.g. scientific institutes, obtain data through an NDC. The NDCs can set up tailor-made standing subscriptions and they can also make on-demand requests! It is also possible to connect to the EIDC on the World Wide Web and browse through the products and some of the data.

- System monitoring. The EIDC monitors the status of all stations, communications and EIDC systems and produces a daily summary of the performance. Problems are recorded in log files and in the database.

- Documentation. All functions of the EIDC should be completely documented to make it possible for the NDCs to reproduce the results of the EIDC.

4.2 Data Processing Operations

Many of the functions envisaged for the future IMS/IDC have already been implemented at the GSETT-3 EIDC. After more than three years of GSETT-3 development and experimental operation, including full-scale continuous operation for the past year and a half, the major problems have been solved and the functions are working well, with a few exceptions. The experience of GSETT-3 is that it generally takes up to one year after the implementation of a new function to solve all related problems.

4.2.1 Overall operational experience

The EIDC has been in full operation on a 24 hours, 7-day per week basis, since January 1, 1995. Due to a failure of the disks containing the operational database and a subsequent failure of the mirrored disk system used at that time, the EIDC was out of operation for 7 days in May 1995. With this single exception, the EIDC has processed and analysed data from every dataday and produced 20,224 analyst reviewed events during 1995. However, for days with excessive seismicity or after serious hardware problems the EIDC has not made a complete analysis.

The final step in the EIDC analysis and one of the most time consuming is to scan the raw waveform data for events missed by the automatic system. This step was sometimes not performed during 1995 due to lack of time, but from January 22 to June 10, 1996 the analysis has in principle been complete for all datadays although the EIDC during a large aftershock sequence in February used so called abbreviated analysis of the aftershocks. On June 15 the EIDC changed to a 5-day per week schedule for interactive analysis but still with the intention of analysing all datadays.

Around 50 persons, including 8-10 international visitors, are presently working at the EIDC with operations and development relating to the seismic technology. A large part of the development effort is done outside of the EIDC.

4.2.2 Data acquisition, archiving and data handling

Most of the functions of the EIDC, like data acquisition, archiving and distribution, are now completely automatic and require only monitoring and restarting/reconfiguration in case of a software or hardware error. This automation is necessary to avoid excessive costs and to provide rapid services at all times. Only the analysis requires a very considerable human effort after the initial automatic processing.

Continuous data from more than 40 primary stations, many of them arrays, has been received by the EIDC with only minor problems in spite of the complexity of the software. The development of some design features planned for this software, like handling of calibration signals and an improved user interface, remains, however, incomplete.

The automation of data handling has in general worked well. Most of the problems were linked to the insufficient capacity and reliability of the previous mass storage device, which was replaced in May 1996. The previous mass storage device could only contain 3-4 months of data and it was too slow to handle the demand. The new device has a 24 times larger on-line capacity and is expected to be much more reliable. Data prior to May 1996 is still on the old system. It was also found that the software handling messages could lose messages and e.g.cause requests from NDCs to be neglected. The message system was made more robust in December 1995 and there is no indication of lost messages after this date.

4.2.3 Automatic signal detection and event location.

High quality of the initial, automatic analysis is important because:

- the automatic bulletins are of interest to the NDCs as they are produced within 10 hours of an event occurrence;

- a relatively good initial location would lead to an optimisation of the requests of data to auxiliary stations;

- a limited number of false and missed events would decrease the analyst work load;

- the automatic bulletins provide an objective (although sometimes inaccurate) information about an anomalous event.

During GSETT-3 three different automatic event lists are produced: the AEL based only on primary data, the ABEL and the DEL which also contain auxiliary data. The DEL is the best automatic event list, produced around 10 hours after the events, and it is used as the starting point for the interactive analysis. The quality of the automatic processing, as discussed in the following, is judged from the quality of the DEL.

Much work has been done during GSETT-3 to improve the automatic processing. For the first step, detecting signals, a new program called DFX, Detection and Feature Extraction, was developed and implemented in January 1996. DFX has a much improved quality control of the waveform data and after its introduction the number of false detections has decreased considerably. A very time-consuming development task is to tune the automatic detectors so that the optimal detection is achieved. This task involves choosing frequency bands, array beams and detection thresholds for each station individually. Still however, about one-third of all arrivals in the REBs are being added by the analysts and were therefore missed by the automatic detectors. A precise timing of the onset is necessary to reach a precise location of the event. During 1995 only 20% of the automatically determined onset times were approved by the analysts. After DFX the percentage has increased to 50%.

Based on the onset time and phase identification of the detections, events can be formed and located. A new program called GA, Global Association, has been developed and was implemented in March 1996. The main advantage of GA is its computational efficiency which will make it possible to process data from the full IMS networks even on days with large aftershock sequences without causing delays. The quality of the automatic event lists has also improved partly thanks to DFX and GA. Presently around half of the events in the best of the automatic event lists (the DEL) are considered by the analysts to be false events or events with insufficient data. Of all the events in the REBs 15% are added by the analysts and were thus missed by the automatic system. This is a significant improvement over the situation in 1995 when around 30% were added. During the interactive analysis depth is modified for 60% of the events and the location for all events.

The effort to improve the processing should continue (and might require 5-10 persons) in order to increase the quality of the automatic products. To obtain such a high quality of the automatic processing that the number of analysts can be decreased is however a very long term goal (if it can be achieved at all).

4.2.4 Retrieval of auxiliary data

The task of the auxiliary network is to improve the location and source characterization of events formed by the primary network. The first automatic event list is only using data from the primary stations, but automatic requests for additional data are then sent to a selected number of auxiliary stations. The selection is made based on the events in the first list. The locations of the events are then modified based on the data from the auxiliary stations. This process is repeated so that additional requests, if there is a need, are based on the events in the second list and a third automatic event list is created.

The selection of auxiliary stations is one of the most frequently upgraded processes at the EIDC. The goal of the selection process is to get all useful auxiliary data for an event, while keeping the communication cost as low as possible by minimizing the volume of data requested. During the last six months of 1995 the IDC sent around half a million requests for auxiliary data. Many problems were found during GSETT-3, causing 37% of all REB events to be located without auxiliary data:

- The selection is based on the automatic event lists which contain many false or mislocated events. In addition many real events are missed by the automatic processing and have to be added by the analysts during the interactive analysis. Added or seriously mislocated events will in general not be able to use the auxiliary stations as there are no requests made in connection with the interactive analysis. On the other hand, useless requests will be made for the false events and this will increase the communication cost of the EIDC. The quality of the automatic event lists has increased and this has improved the situation but rather marginally. To fully utilize the auxiliary network there should, in addition, also be a final retrieval of auxiliary data based on analyst reviewed events followed by a second pass of interactive analysis.

- There have been many technical problems in retrieving data from the auxiliary stations. This has significantly improved during GSETT-3 although there still are some problems especially with newly added or remotely located stations. Presently around 90% of all requests are answered.

- The algorithm used at the EIDC to select auxiliary stations has been improved but is still in need of further improvements. The retrieval of auxiliary data at the EIDC has up to now been focused on improving the location, but the task of improving the source characterization is equally important. This might require more emphasis on retrieving S phases, depth sensitive phases and surface waves.

4.2.5 Interactive analysis

During the first months of 1996, 11 seismologists were reviewing the results of the automatic processing and producing the REB. This seems to be the minimum number of experienced analysts required to produce the REB within 48 hours of the end of the dataday. Interactive analysis is absolutely necessary to obtain a high quality product.

The quality of the final product of the analysis at the EIDC, the REB, has in many respects been very good. Comparisons with regional bulletins, where available, indicate that nearly all event solutions in the REB correspond to genuine seismic events. In regions where detailed investigations have been undertaken with information from dense local networks, some (but very few) of the events in the REBs have been shown to be fictitious. In the following sections the methods for determining the event parameters are discussed in more detail.

4.2.6 Event Location

The GSETT-3 has allowed the initial testing of the accuracy of the locations of seismic events determined by the experimental EIDC procedures. As part of the location procedure an estimate of the precision of epicentre coordinates is currently calculated and reported in the REBs. This estimate should not be confused with a location accuracy which reflects the actual location error for a known location. The accuracy was estimated by comparing the difference between the location determined by the EIDC using data from primary and auxiliary stations participating in GSETT-3 and locations determined independently, either by known locations (such as industrial explosions at known mine sites) or by seismic locations provided by local or regional networks. In the majority of cases, the GSETT-3 locations are more uncertain than 1,000 km2. There are two basic reasons for the large errors in the GSETT-3 locations: the GSETT-3 network does not represent homogeneous or optimal coverage and the GSETT-3 network has not been calibrated. Some small scale calibration experiments have been carried out in areas where the GSETT-3 network approaches that of the IMS. In these experiments, the locations using the calibration information are significantly improved.

4.2.7 Depth determination

Presently most events in the REBs are assigned a default depth of zero kilometres irrespective of their true depth. This is not useful for source characterization. Calibration of the networks should make it possible to determine the depth for more of the events but there is also a need for developing better methods for determining the depth by e.g. finding more depth phases by stacking waveforms, by using long periodic spectra and by incorporating 3-D velocity models. However, the Ad Hoc Group recognizes that in this respect there is a limit to what can be achieved.

4.2.8 Amplitudes and magnitudes

Amplitudes are measured automatically. The analysts do not routinely modify the automatic measurement. It is therefore difficult to estimate how good the automatic determination is. Amplitudes cannot currently be determined for phases added during interactive analysis. The implementation of an event-based option in the new DFX program will make this possible. Due to the importance of amplitudes for source characterization more attention should be given to obtain reliable amplitudes for all phases.

Using amplitudes and periods the EIDC computes magnitudes, presently three different kinds of magnitudes: ML, mb and Ms. The goals are to obtain magnitudes that can be automatically and reliably computed by the EIDC, which are comparable to what is produced by seismic agencies and which are of the greatest help for the NDCs in their verification task. Efforts have been initiated to address this issue, but further attention will be required.

4.2.9 Long period data

During 1995 the EIDC started to use also long period data to compute the surface wave magnitude, Ms. This magnitude is of great value in characterizing events but is difficult to determine for weak events. Presently this magnitude is computed for less than 10% of the events and the methods for detecting and associating surface waves to events should be improved. Data at regional distances could be used to further increase the number of events with associated surface waves, and work is underway on this.

4.3 System Operations

4.3.1 Adherence to time schedules

The improvement of the automatic processing has made it possible for the EIDC to follow the strict time schedule, even during periods of increased seismicity, like an aftershock sequence. Hardware failures affecting the key components could however still lead to delays. A higher degree of hardware redundancy is needed in the operational system.

The expansion of the network of stations to the full IMS network could require more resources in order to adhere to the time schedule. The introduction of the new software for automatic event processing should at least make it possible for the automatic part of the processing to follow the time schedule. Only a very limited experience exists on the fusing of different technologies into one final product and the impact this has on the time schedule.

4.3.2 Subscription and data distribution services

The NDCs can presently subscribe to the automatic event lists (except the DEL) and the REB, and also to reports giving the status of communication links and stations. The NDCs can furthermore obtain in near real-time all of the continuous waveform data that the EIDC is receiving.

The forwarding of continuous data to NDCs has had mixed success during GSETT-3, although very few NDCs have asked for this kind of subscription due to the large volume of data that has to be handled. Numerous small bugs in the forwarding software have been found and corrected. The primary improvement planned is to keep track of gaps in the continuous data, so that these can be filled later. Forwarding of auxiliary data should also be possible.

The other subscription services have worked well during GSETT-3 and some useful options, like the possibility of selecting only events in certain regions, have been added. It remains to give the NDCs waveform segments associated to the events in the REB and also to add a characterization bulletin with source characterization parameters for each event. These additional products are necessary if the NDCs shall be able to perform their verification tasks. The NDCs should also have the possibility to receive the products immediately instead of once a day.

The contents and layout of the information given on the World Wide Web have been greatly improved and are now found to be very useful. NDCs with an experience in the database query language have found direct access to the EIDC database to be a very rapid way of obtaining information although this is not a user-friendly method.

The performance during 1995 of the AutoDRM function of the EIDC, which is used to answer ad hoc requests, would not have been acceptable for an operational EIDC. Requests have been ignored, delays of many hours have been common and the EIDC has also sometimes deleted the answers before the NDCs got the oppurtunity to read them. The excessive delay times might have been caused by hardware limitations in the mass storage device that was replaced in May 1996. The option of obtaining waveform segments associated to a specified event has not been implemented making it more cumbersome for the NDCs to request data. A segmented data archive that should satisfy most event-based requests is under development. Some other useful options are also lacking, e.g. requests of all detections even if they are not associated to an event by the EIDC. During 1995 the EIDC sent around 5000 answers with a total volume of data of 2 Gbytes. It could be expected that this will increase substantially when the system is operational and the use of requests has been made more user-friendly.

4.3.3 System monitoring

Status reports have been sent regularly to subscribing NDCs. A WorkFlow diagram giving a near real-time picture of the processing at the EIDC is available on the Web, making it possible for the NDCs to detect problems with the processing of their stations within minutes. An example of such a diagram is shown in Fig. 4.1. The EIDC has also an extensive internal monitoring which should be improved further so that problems are detected and remedied immediately.

4.4 Procedures that need further testing

A few of the functions envisaged for the IMS/IDC are presently not implemented at the EIDC or were implemented so recently that only a very limited experience exists on possible problems with the implementation. These functions include:

- Authentication. The concept of adding a digital signature to the data using a private key and then verifying the data using a public key has been tested for one sensor and proven to work, but general application has yet to be carried out.

- Event characterization. Initial development of routines to compute a comprehensive set of event characterization parameters has been done. The implementation of these routines into the EIDC processing and products was however done so recently that there is nearly no

NDC experience on possible problems with the routines and the usefulness of the parameters. There might be a need for some additional parameters, and distance corrections and regional dependence have to be added to increase the usefulness. An event characterization bulletin will be a new product of the EIDC.

- Screened bulletin. This concept involves applying a set of standard criteria to screen out events considered to be consistent with natural phenomena or non-nuclear, man-made phenomena. The concept has been demonstrated, but the usefulness depends to a large extent on the event characterization parameters and there is therefore very little practical experience with this EIDC product.

- Executive summary bulletins. This concept implies providing high-level, condensed summaries of IDC data, products and operational status. The concept has been demonstrated, but has not yet been tested operationally.

- Threshold monitoring. This is a method for providing a continuous assessment of the upper magnitude limit of any seismic event that might have occurred at a specified time and place. An experimental version has been developed and demonstrated, but the function is not yet implemented operationally at the EIDC.

- Other technologies. The EIDC has recently started to process data from other technologies, taking advantage of the processing developed for seismic data. Processing of hydroacoustic data is closest to the seismic processing and the integration has started. Much work has however to be done, especially in the integration of data from all four technologies into one single, fused bulletin.

- Documentation is discussed in Chapter 6 of this report.

4.5 Personnel and Training

4.5.1 GSETT-3 EIDC personnel requirements

The EIDC is staffed with professionals of the highest quality. Currently, 65 people are working at the EIDC. It should be emphasized that specialized knowledge and experience are required for most of the positions. The analysts have a bachelor degree in geophysics or equivalent background and several years of experience with seismic analysis. The hardware and software engineers have a bachelor degree in computer sciences. Many of the other positions require advanced degrees in geophysics.

4.5.2 Training

During GSETT-3 7 international visitors have received on-the-job training in different aspects of the EIDC operations and a further 11 experts have taken part in the development and evaluation of the EIDC.

The international visitors have all had a solid background in seismology and a large experience at their home institutes. To be effective at the EIDC required an additional training of 6 weeks up to 6 months depending on the position.

4.6 Recommendations

The seismic processing at the EIDC has evolved as a result of GSETT-3 and is now in many regards closer to what can be expected of an operational IMS/IDC. Further improvements are, however, necessary. On a long term basis, there should be a continuous development at the EIDC to take advantage of the scientifical and technical development. The performance of the system should be continously evaluated to ensure the quality and usefulness of its products. The training program at the EIDC has to be expanded to meet the envisioned need at the operational IMS/IDC. The EIDC can also make important contributions in training of staff at national facilities, to prepare for the IMS.

The quality of the EIDC operation has sometimes been downgraded by hardware and software failures. It is important that an operational IMS/IDC has sufficient hardware redundancy so that the operation can continue without interruption or be resumed without loss of data. The new version of mirrored disks should hopefully contribute to this but additional measures should be taken. As an example the IMS stations or the corresponding NDCs should, according to the specifications, have buffers containing one week of data. Even in the case of a serious failure at the IMS/IDC, there should therefore always be the possibility of retrieving lost data by requesting the stations/NDCs to retransmit. Software for doing this automatically has however to be developed; presently it is difficult for the EIDC to utilize the station/NDC buffers. The data, primary and auxiliary, at the IMS/IDC should be as complete as the data at the stations/NDCs.

All software to be used at the IMS/IDC should be tested extensively before implementation in the operational system. The experience from GSETT-3 is that it is difficult, even with extensive testing, to find all deficiencies in new software.

As discussed in previous sections, further development of the EIDC is necessary. The most important new functions to add are calibration of the network, extensive source characterization and authentication. It should also be made more easy for the NDCs to obtain waveform segments and source characterization parameters for each event, either by subscription or on demand requests. Merging of the four technologies to obtain a fused event bulletin requires an extensive development effort. The existing functions at the EIDC could also be improved, e.g. the selection of auxiliary stations, depth determination and use of long-periodic data. Further tuning of the automatic processing should be done. It may be useful for the EIDC, and also in the future for the operational IMS/IDC to solicit technical suggestions from NDCs and to review such suggestions with a view toward improving the standard procedures.

A key result of the GSETT-3 with respect to event location accuracy is two-fold: First, the importance of establishing the full IMS network of primary and auxiliary stations as proposed to provide significantly improved global coverage over what is obtainable with the current

GSETT-3 network. Second, the recognition that the process of improving the network locations will require an extensive calibration of the whole IMS network, region-by-region. Taking into consideration the size of the proposed IMS seismic network, this would be a large, but necessary undertaking. A network calibration program would require information currently available in individual national earthquake monitoring programs. In seismic areas (including mining areas) calibration should be able to rapidly improve the location accuracy when the IMS network is completed. Calibration, especially in regions with low seismicity will continue to improve as more ground truth data and more detailed regional earth models become available. Taking advantage of information on large industrial chemical explosions would greatly accelerate this process and could rapidly improve the location accuracy of the IMS network in these areas.

5. Seismological Performance and Capabilities

This chapter evaluates GSETT-3 in terms of its seismological performance. In particular it discusses the products of the EIDC in statistical terms and in comparison with accepted seismological practice and with other seismological data sources. Due to limited resources during GSETT-3, little effort has been devoted to new seismological concepts. Priority has been given to the production of a comprehensive daily bulletin using traditional seismological methods. The discussion follows, in sequence, the main processing steps at the EIDC. Each step is reviewed and a comment is given on the level and direction of effort that will be required to reach an operational level compatible with the envisaged goals of the future IMS/IDC. GSETT-3 began on 1 January 1995 and considerable improvements have been made during the course of the experiment; therefore only the results obtained between 1 January and 31 May 1996 will be studied in this review.

5.1 Present status and implementation of seismological methods

5.1.1 Signal Detection

In late January 1996 new automatic detection software was installed at the beginning of the data processing sequence at the EIDC. More recently, the tuning of the detection processing parameters for each station have led to improvements in the detector performance and in eliminating false detections caused by spurious data. Nonetheless, on average, only 6.4% of the detections at primary arrays and 6.8% of the detections at primary 3-component stations during the study period eventually were associated with events in the Reviewed Event Bulletin (REB). Automatic detections comprise 67% of all arrivals reported in the REB. Of these 35% come from primary arrays, 22% from primary 3-component stations, and 10% from auxiliary stations. 33% of the detections are added manually by analysts.

Comment: Although automatic detection processing can never be made completely error free and efficient, the current system needs considerable more work. Fine tuning of the detection processor on a station by station basis is required. Additionally, alternate detector algorithms may improve performance.

5.1.2 Post-detection processing

Since the installation of new software the automatic timing and identification of seismic phases has improved markedly. Manual re-timing of automatic "picks" has been reduced, now affecting around 50% of the automatic detections in the REB. Phase identification has also improved with the results shown in the following table where the percentage of phase identifications in the REB (columns) are compared with phase identifications made automatically (rows). For example: 92% of the phases automatically identified as PKP remain as PKPs in the REB, 4% are changed to P, etc. Note that only the main phases found in the final bulletin and percentages above 1.0 are given. (Px, Sx, and Tx refer to unidentified phases of the P, S, and teleseismic type respectively.)

TABLE 5.1

AUTO / REB	P	PKP	S	Pn	Pg	Sn	Lg	Rg
P	97%	4%	8%	31%	2%	-	-	-
PKP	-	92%	-	-	-	-	-	-
S	-	-	14%	-	-	6%	-	-
Pn	1%	-	4%	66%	18%	-	-	-
Pg	-	-	-	3%	68%	-	-	-
Sn	-	-	13%	-	-	61%	8%	-
Lg	-	-	2%	-	-	2%	61%	8%
Rg	-	-	-	-	-	-	-	64%
Px	-	-	-	-	10%	2%	2%	-
Sx	-	-	50%	-	1%	25%	27%	28%
Tx	1%	3%	8%	-	-	3%	-	-

Comment: The quality of the automatic phase identification is excellent for teleseismic P-type phases. The performance degrades for regional phases with about two-thirds of these being correctly identified. The poorest automatic results are obtained for teleseismic S phases, with only a 14% success rate. More work is needed in the refinement and tuning of the phase identification software for regional and S-type phases.

5.1.3 Event definition

The event definition criteria are based either on a number of P-type phases or on a weighted count of defining parameters, such as arrival time, azimuth, and slowness, of detected seismic phases. The definition criteria have not changed during GSETT-3. These criteria are less restrictive for the automatic bulletins (weighted count greater than or equal to 3.6) than for the REB which requires either 3 first arriving phases at primary arrays or a weighted count greater than or equal to 4.6.

During the study period, 45% of all automatically formed events were rejected by the analysts, and 25% of the events in the REB were added by the analysts. However, the recent implementation of new association software has caused a reduction in the number of events added by analysts (see section 4.3.3).

Comment: The event association software needs further refinement. Too many false events are automatically formed and, more importantly, too many events are missed by the automatic process and need to be added by the analysts.

5.1.4 Auxiliary data retrieval

The increase in the number of auxiliary stations and improvements of the auxiliary data retrieval system over the course of GSETT-3 have resulted in an increase in the number of events located using data from these stations. 63% of events in the REB are now located using some auxiliary station data. The average number of auxiliary stations contributing to these events is 3.5. Both statistical evidence and special case studies indicate that the selection of auxiliary stations from which data is to be retrieved is suboptimal from the point of view of maximizing location accuracy.

Comment: In order to fully realize the location capability offered by the primary/auxiliary station concept, azimuthal coverage at regional distance should be optimized for each event. To this end more attention should be given to auxiliary station reliability, the algorithm that selects auxiliary station data, and signal/noise ratio estimation for auxiliary stations. It may also be advisable to adopt a step-by-step approach in auxiliary data retrieval, basing station selection on the stepwise refined location. This would involve giving the analysts the capability to request and review auxiliary station data.

5.1.5 Event location

The event location algorithm currently used at the EIDC applies a non-linear inversion of wave propagation time, as well as array azimuth and slowness values to determine the location and depth of seismic events. It also provides an estimate of location uncertainty (or precision) in the form of an error ellipse, an area on the surface of the earth within which there is a 90% chance that calculated epicenter should fall. However, without calibration, the true location of the event may not fall within the theoretical error ellipse as has been shown by many national contributions during GSETT-3. In general, the location uncertainty of any given event is greater when the azimuthal coverage of the stations used in the location is poor. Correspondingly, experience in GSETT-3 has shown that data from well distributed auxiliary stations contribute to a substantial reduction of the error ellipse size, particularly over continental areas.

The following table (5.2) gives the percentage of events in various magnitude ranges as a function of location precision. For example, for events in the magnitude range 4.0-4.5, 28% have error ellipses less than 1,000 square kilometres (sqkm); 46% have error ellipses between 1,000-10,000 sqkm; and so on. There is a clear relationship between event magnitude and size of the error ellipse; larger events are usually recorded by more stations with a greater azimuthal distribution. Due to the uneven station distribution, location uncertainties vary greatly from region to region; however, a few general conclusions can be drawn with basis in this table. For example, by adding the numbers of events in the appropriate rows, it can be calculated that about 21% of the total events have error ellipses less than 1,000 sqkm; about 35% of all the events have error ellipses that exceed 10,000 sqkm. Similarly, by restricting the calculations to events above magnitude (mb) 4.0, it is found that 35% have error ellipses less than 1000 sqkm; 23% have error ellipses greater than 10,000 sqkm.

TABLE 5.2. Percentage of events within each magnitude (mb) range as a function of error ellipse size. Absolute numbers are in parentheses. Data are from 1 January 1996 - 31 May 1996.

Error ellipse size in square km.	< 4.0 mb	4.0-4.5 mb	4.5-5.0 mb	5.0-5.5 mb	> 5.5 mb
< 1,000	15% (1129)	28% (808)	57% (344)	91% (101)	100% (25)
1,000- 10,000	43% (3238)	46% (1347)	32% (193)	6% (7)	- (0)
10,000- 100,000	30% (2255)	19% (549)	9% (53)	3% (3)	- (0)
> 100,000	12% (909)	7% (211)	2% (12)	- (0)	- (0)

Accurate depth estimation is part of the event location process and is important in the context of event "screening" at the IMS/IDC under a CTBT. During GSETT-3 event depth has been determined by one of the following methods in order of decreasing reliability: constrained by depth phases (7% of the events in the REB during the study period), automatically determined during the location process (23%), arbitrarily fixed or restrained either by the event location process or by an analyst (70%).

Comment: The location capability, as measured by the number of events located with less than 1000 sqkm uncertainty, is showing only slow improvement. Even under the assumption of the more homogeneous station distribution envisaged for the IMS much work remains to be done. Of the events above magnitude 4, about 35% are located with an error ellipse of less than 1,000 sqkm. Accurate depth estimation will be very important in IMS/IDC event screening. Yet during the study period 70% of events in the REB had depths arbitrarily assigned, either automatically or by an analyst. It is very important that the EIDC begin to carry out its plan for improving event location through calibration, an initial version of which was presented in Annex 2, CD/1398, and through the use of other procedures.

5.1.6 Source parameters

A magnitude estimate, either mb or ML, is provided for almost 99% of the events in the REB. Body-wave magnitudes, mb, are unavailable for about 10% of the events reported in the REB, mainly because mb is currently calculated only for events with at least one teleseismic P-phase detection. Local magnitudes, ML, are calculated only for events with at least one station within 2000 km from the source, and are reported for about 41% of the REB events. The reason why a few events have not been assigned any magnitude value is the current lack of appropriate post- analysis processing at the EIDC.

Comparison with external bulletins such as the Preliminary Determination of Epicenters (PDE - a weekly bulletin published by the National Earthquake Information Center in Boulder, Colorado) has become less definitive because the PDE has begun to incorporate amplitude and period measurements from GSETT- 3. However, the PDE magnitude estimates are based also on a large volume of independent data. In general REB mb values range from about .21 - .25 magnitude units less than the PDE. This bias leads to an overestimation of the number of small events in the REB and an optimistic assessment of the detection capability of GSETT-3 if estimation is based on the magnitude/frequency relationship. Conversely, the REB tends to overestimate the ML magnitude, particularly in Europe, when REB ML values are compared with those from national networks. In individual cases this error can be up to a full magnitude unit.

The surface wave magnitude, Ms, will be important in event screening at the IMS/IDC. During the study period less than 8% of the events in the REB had associated Ms values, and less than 5% had Ms values based on 2 or more or more stations.

Comment: New magnitude computation procedures have been introduced at the EIDC and more time may be needed to evaluate the impact of these new procedures. However, the EIDC should make a strong effort to determine why the mb and ML values it reports differ from those reported in other bulletins for the same events. The Ms reporting procedures used during GSETT-3 need greater attention, considering that Ms is a parameter which is proposed to be used in event screening.

5.2 General seismological performance during GSETT-3

Performance is a measure of how well the network has served its purpose, namely to detect and accurately locate seismic events. Performance can only be determined in regions that exhibit ample seismicity and where seismic reference bulletins are available. Local or regional reference bulletins submitted by NDCs as supplementary data ("gamma bulletins") are potentially the most accurate, but are as yet quite heterogeneous in coverage, quality and delay of production. For the observation of long-term developments on a global scale, comparison of the REB of GSETT-3 to the PDE is most useful. This approach, the results of which are presented in Figure 5.1, yields values that are averaged over world seismicity as it is reported in the PDE, and not averaged over the earth's surface, as might be preferred.

Regional studies have shown that the REB has become much more complete toward small magnitudes than the PDE in the whole Pacific region. Therefore the steep descent of the detection thresholds since December 1995 seen in Fig. 5.1 is mainly representative of regions like Alaska, California, Europe and Central America, where GSETT-3 station coverage has improved significantly relative to the PDE network. In particular, it is no longer representative for Pacific seismicity. On the other hand, the diagram in Fig. 5.1 on average location performance (using all events common to the REB and the PDE) has remained rather stable, which partly reflects that there are now many more small events in the common data set. It should, however, be noted that the location diagram would tend to be slightly positively biased from May 1995 onwards, when PDE started to integrate REB arrivals.

These caveats must be kept in mind when interpreting Fig. 5.1. It presents the observed detection thresholds and, as a measure of location accuracy, the equivalent circle areas obtained by taking the differential location vectors as radii. (An equivalent circle area of 1000 sqkm has been mentioned as a target value for the IMS).

Note that the median (or 50%) values have the advantage of being less influenced by outliers, whereas the 90% values are closer to generally acceptable notions of reliability. The detection thresholds in Fig. 5.1 are based on PDE mb magnitudes. REB mb values have a stable negative bias of about -0.25 units compared to PDE, as mentioned above in section 5.1.6.

5.3 Estimated GSETT-3 capabilities

Capability is a measure of how well the network is able to detect and locate seismic events, wherever they might occur. In order to interpolate observed performance into non-seismic regions, a probabilistic network simulation code was calibrated to observed performance in a number of regions. The map in Fig. 5.2a shows the interpolated network detection capability as estimated for March 1996 in terms of the 90% detection threshold. The GSETT-3 primary network at that time is shown as dots. The detection threshold is about or below mb 3.6 in northwestern Europe, North America, Central Asia and Australia. It is below mb 4.2 in most South America and between 4.2 and 4.6 in most of the southern hemisphere oceanic regions. Fig. 5.2b shows the interpolated network location capability as estimated for March 1996 in terms of the 90% equivalent circle radius for a magnitude 4 event. The combined primary and auxiliary GSETT-3 network at that time is shown as dots. Note that a radius of about 17 km corresponds to the 1000 sqkm target for IMS. Equivalent circle radii of under 30 km (areas under 2800 sqkm) are obtained in Europe, North America and Australia; radii are under 50 km (areas under 7800 sqkm) for all continental areas above 40 deg N latitude. Location capability in South-East Asia, India, Africa and South- and Central America is quite variable, with all continental areas well below a radius of 200 km (125,000 sqkm), while most of the southern oceans and Antarctica remain above 400 km (500,000 sqkm).

Comment: Both detection and location capabilities are presently very heterogeneous. Network simulation has shown that this situation will improve as network geometry approaches that of the IMS. Network tuning and calibration will, however, be required to bring detection thresholds and mislocations down to levels expected for an operative IMS.

5.4 Recommendations

In the specific comments given above detailed recommendations can be found where further work needs to be focussed. These areas include: the use of auxiliary stations, location and depth estimations, magnitude determination, quality assurance, and general calibration of the network. These are issues that have been singled out for attention in previous reports of the GSETT-3 Working Group on Evaluation. Solving these problems will not be easy and will require considerable work and attention to detail.

Additional, more general recommendations are provided below. Action on these recommendations will ensure that the EIDC operation can smoothly be transferred to the IMS/IDC.

General recommendations:

1. The EIDC should consider concentrating limited resources on improving its procedures and products at the expense of producing a routine, daily bulletin. In the long view, effort expended now in improvements will have a much greater impact than effort spent in producing a daily bulletin.

2. Following the above recommendation, the EIDC should direct additional resources to the implementation of the GSE network calibration plan, an initial version of which is given in CD/1398 Annex 2.

3. Increased effort is needed in the fine tuning of the automatic processing in order to reduce the load on the analysts.

4. Automatic consistency checks should be tested to reduce the number of false events.

5. A formal quality assurance plan should be developed for the IMS and the future IMS/IDC should be assigned the resources required to implement it.

6. GSETT-3 experience has shown that an independent scientific review panel would be desirable. This panel could meet periodically to review IMS/IDC procedures, results and quality assurance practice, make recommendations, and evaluate the impact of these recommendations once implemented.

7. Expanded use of data from auxiliary stations is strongly encouraged. Expanded use of data from these stations can improve event locations, depth determinations, and magnitude estimates.

6. Documentation

Comprehensive technical documentation of all facilities and procedures as well as the hardware/software implementation has been an important part of GSETT-3. The GSE has developed and maintained an extensive set of documentation, available both as hard copy and in electronic form. The GSETT-3 experience has demonstrated that such detailed documentation is essential.

6.1 Structure of the Documentation

The GSETT-3 documentation is contained in the Group's Conference Room Paper 243, and comprises four main volumes with numerous technical annexes:

Volume 1: Plan

This volume of the documentation has remained in the same form since its release in July 1995. Tables and figures of participating stations have regularly been updated during the conduct of GSETT-3 and included in the GSE progress reports.

Volume 2: Operations

Upon request from the GSE members, several modifications have been made recently to the EIDC part of the operations documentation, the latest being a revised chapter on magnitude computation completed in May 1996. The database description is being thoroughly reviewed in order to make the use of this document easier.

There is a need for further updating of parts of this documentation, such as the "IDC User Guide" and "Message Formats & Protocols."

Volume 3: Facilities

This document provides up-to-date information about the stations that are currently part of the GSETT-3 network.

Volume 4: Evaluation

This part of the documentation is being updated as new results from the Working Group on Evaluation become available. Currently, three Evaluation Reports are included.

6.2 Assessment of the Documentation

The extensive documentation described above has formed the basis for operations manuals and procedures for GSETT-3. It also contains technical summaries of EIDC and NDC operations, as well as results from evaluation reports.A hard copy version, comprising about 1000 printed pages, was distributed to participants in July 1995, and periodic updates have been provided since then.

The EIDC has made the entire documentation available in electronic form, and it is now possible to access and update the documentation by using the Internet. The electronic version of the documentation, has proved especially useful during GSETT-3, making it possible to keep the information up-to-date and easily accessible.

Even though an effort of clarification has been made in the latest releases, the documentation in its current state still needs additional work. Parts of the documentation are either not up-to-date or not detailed enough. It has in particular been difficult to keep up with the changes occurring at the EIDC relative to new software releases.

Volume 2 of the documentation will require a thorough review of all sections; some parts are currently being updated. The EIDC has provided a remarkable effort in keeping Volume 3 up-to-date. However, a large amount of information regarding the station characteristics is missing.

NDCs should also verify that they have provided the EIDC with all the required information. A procedure is available at the EIDC which allows NDCs to update such information on-line. It is also desirable that computer programs referenced in the documentation be documented at a hardware and software technical level.

A volume 5 directory has already been created under the documentation tree which includes technical information about the new Global Association software. Other software modules, including software for non-seismic technologies should be included as quickly as possible under a similar structure, since their data are already being processed at the EIDC.

6.3 Recommendations

Comprehensive and up-to-date documentation is essential for proper operation of a system of the scale of GSETT-3. It is understandable that given the time schedule of the GSETT-3 EIDC staff, the maintenance of the documentation has not been a priority so far. However, an effort should be undertaken in order to bring the documentation up to an acceptable level for the future CTBT IMS. The Ad Hoc Group recommends that:

- Work should continue on making the current documentation more complete, especially with regard to information on technical facilities and detailed computer hardware/software descriptions.

- Operational manuals for IMS technologies should take into account the experience accumulated in GSETT-3, and follow the standards set during this experiment.

- The GSETT-3 documentation has been maintained in English only. In preparing for the IMS considerations should be given to translate parts of this documentation into other languages.

- Future IMS documentation should be maintained on electronic form, with access for participants through the Internet or other suitable media.

7. Recommendations on Transition to the IMS

It has been the objective of GSETT-3 to develop and test an experimental International Seismic Monitoring System that can evolve and adapt to support future requirements, and to furnish the CD with such technical experience as can be obtained from this experiment.

The task of constructing an operational International Monitoring System is now gradually coming into focus. Experience gained during the GSETT-3 experiment can provide guidance to achieve a smooth transition to the seismic component of the CTBT IMS.

The present report has been prepared with the goal in mind to assist in this transition. In this chapter we point out, in the form of a condensed list, the most important areas of work lying ahead in order to bridge the gap from an experimental to an operational monitoring system. Some of these points are repeated from previous chapters for ease of reference, other points of a more general nature have been added here.

The list is subdivided into three sections. The first section lists required technical changes which can be implemented relatively soon, as resources become available. The second section lists desired improvements to seismological procedures, most of which have a research component which will take time. Finally, advisable organisational measures are listed.

7.1 Recommended technical changes

- There should be an orderly transition from the GSETT-3 to the IMS network, with the inclusion of stations envisaged for the IMS as they become available.

- There should be a continuous assessment of the contributions of primary and auxiliary stations and recommendations for replacements should be made as appropriate.

- There should be a complete review of the technical specifications of IMS seismograph stations drawing on the GSETT-3 experience.

- Data authentication procedures should be evaluated and implemented.

- The technical characteristics and reliability of stations and communications should be evaluated and upgraded as necessary.

- An IMS data communications concept, more cost-effective than that used in GSETT-3, needs to be established.

- More redundancy and security at all levels of the system (stations, communications, NDCs, and the IMS/IDC) is needed.

- IDC products with emphasis on functionality, reliability, and user-friendliness need to be developed.

- The IMS/IDC should develop improved testing procedures for data processing software.

- Data from other monitoring technologies should continue to be integrated into the EIDC system.

7.2 Recommended improvements to seismological procedures

- There should be continued tuning of the automatic data processing at the IMS/IDC including detection, phase identification, and phase association.

- Improved automatic consistency checks to reduce the number of false events are needed.

- Calibration of the network event location procedures, in accordance with the plan outlined by the GSE, should be carried out.

- Improvements are needed in the calculation of event locations and the specification of the associated uncertainty.

- Improved routines for data retrieval from auxiliary stations are needed.

- The methods for estimating seismic magnitudes (including Ms) should be reviewed and improved.

- Existing event depth estimation methods need to be reviewed and improved; alternative methods should be considered.

- Methods to calculate source characterization parameters should be tested and implemented.

7.3 Recommended organizational provisions

- GSETT-3 documentation should be developed in a form that is appropriate to serve as a complete and up-to-date operations manuals for the IMS and reference manuals for quality assurance and training purposes. The new documentation should be made available electronically, as in GSETT-3.

- The IMS should develop and implement a quality assurance plan.

- A plan for establishing an operational IMS/IDC will be required and should draw on GSETT-3 experience.

- The roles of the NDCs with respect to the IMS/IDC need to be more fully defined including in areas such as: timely and complete data accessibility, data transfer, station monitoring and maintenance, and quality assurance.

- Periodic evaluation of IMS/IDC scientific and technical procedures and products should be carried out by an independent, external panel of qualified specialists.

- A plan is needed for the training of future IMS/IDC and, as requested, NDC personnel.

- Regional workshops and other activities needed to coordinate and promote IMS activities should be pursued.

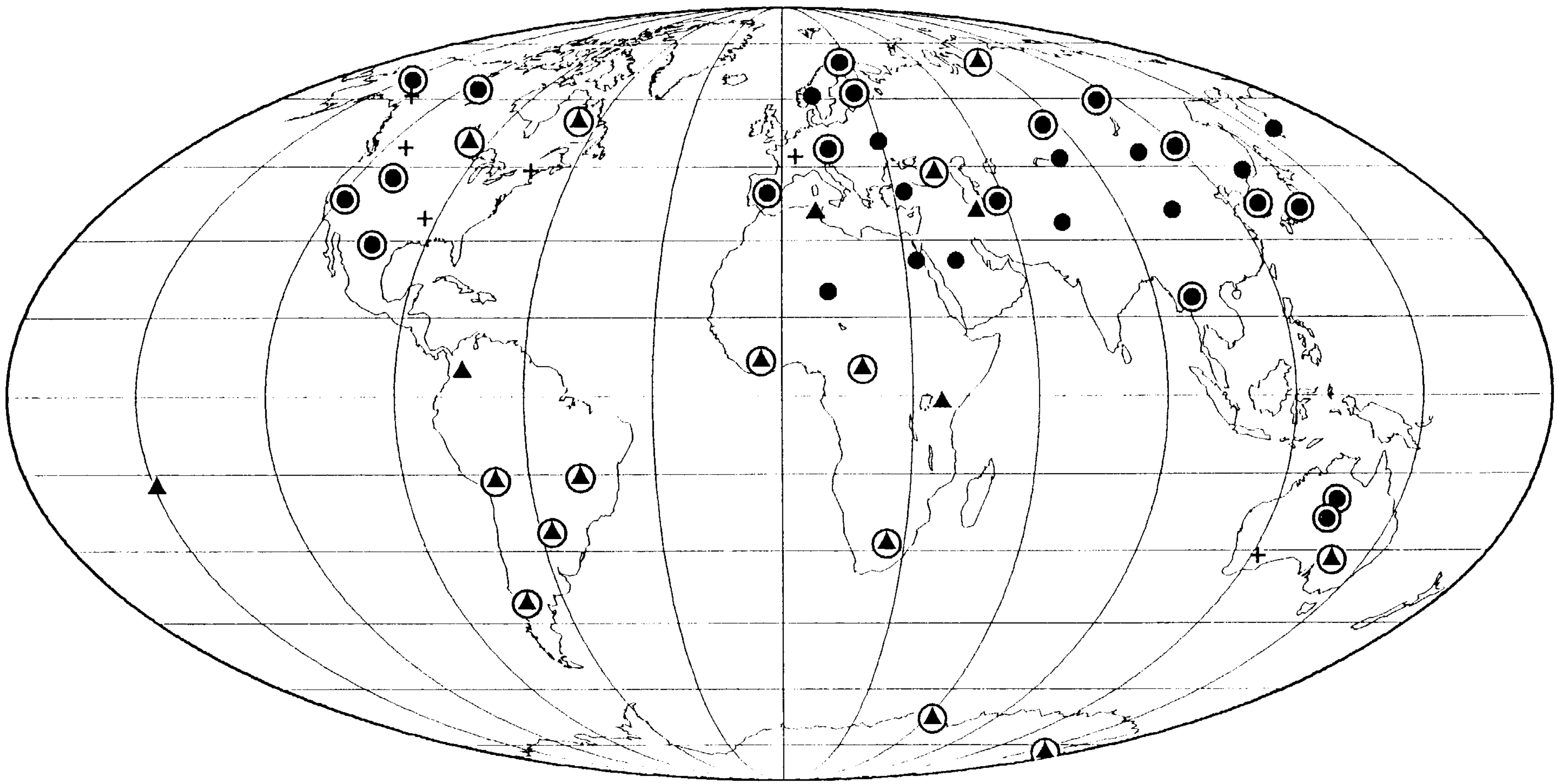


Figure 2.1. Primary IMS seismograph stations. Existing and planned arrays are shown as filled circles and three-component stations as filled triangles. IMS primary stations that are currently participating in GSETT-3 are encircled. GSETT-3 primary stations not envisaged for the IMS are shown as crosses and listed in Table 1b.

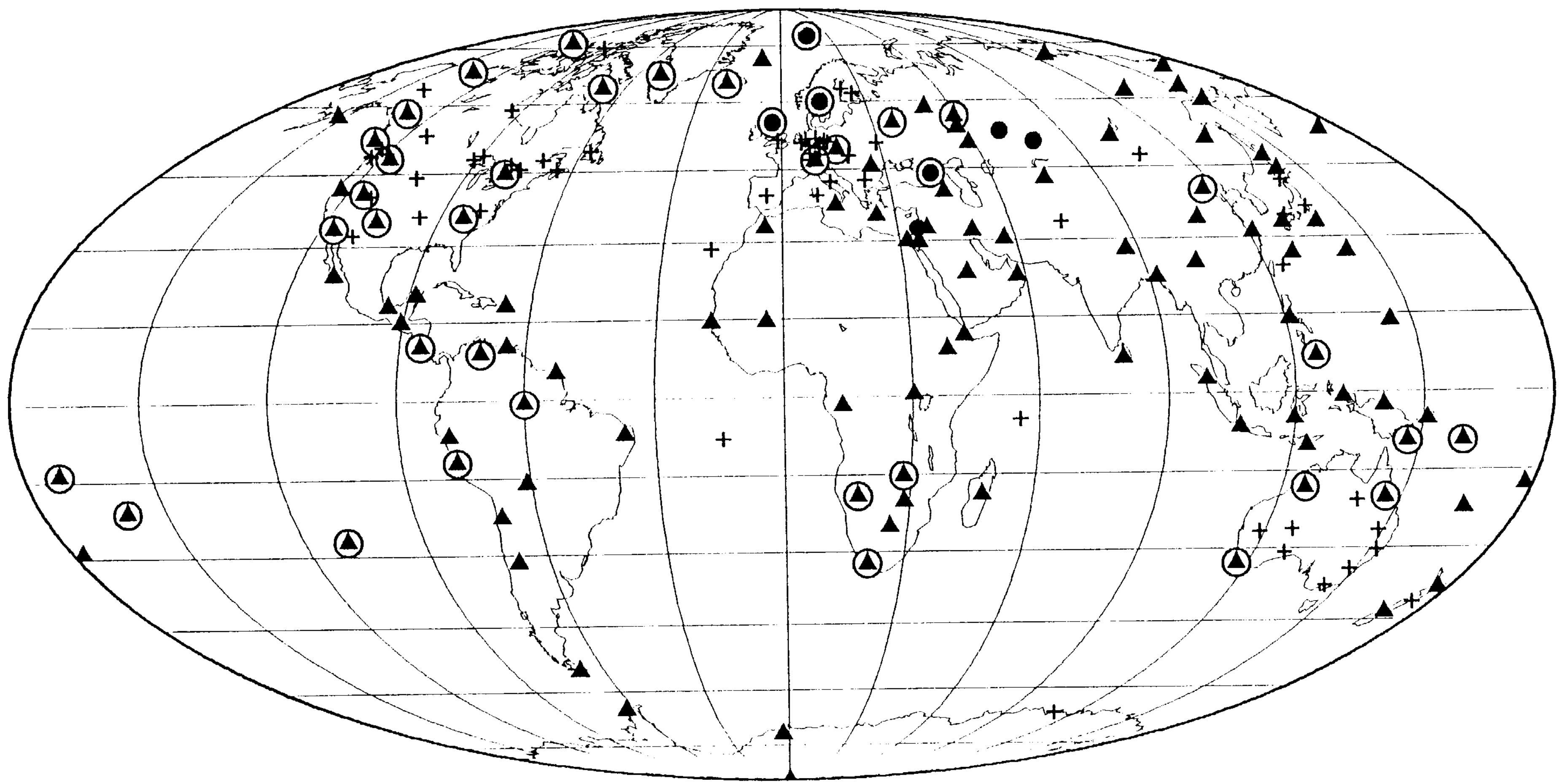


Figure 2.2. Auxiliary IMS seismograph stations. Existing and planned arrays are shown as filled circles and three-component stations as filled triangles. IMS auxiliary stations that are currently participating in GSETT-3 are encircled. GSETT-3 auxiliary stations not envisaged for the IMS are shown as crosses and listed in Table 2b.

Seismic
Monitoring Operation

SEISMIC : OVERVIEW | NETWORKS | PRODUCTS | DOCUMENTATION | MISCELLANEOUS | HELP

Work Flow Monitor

Alpha Status

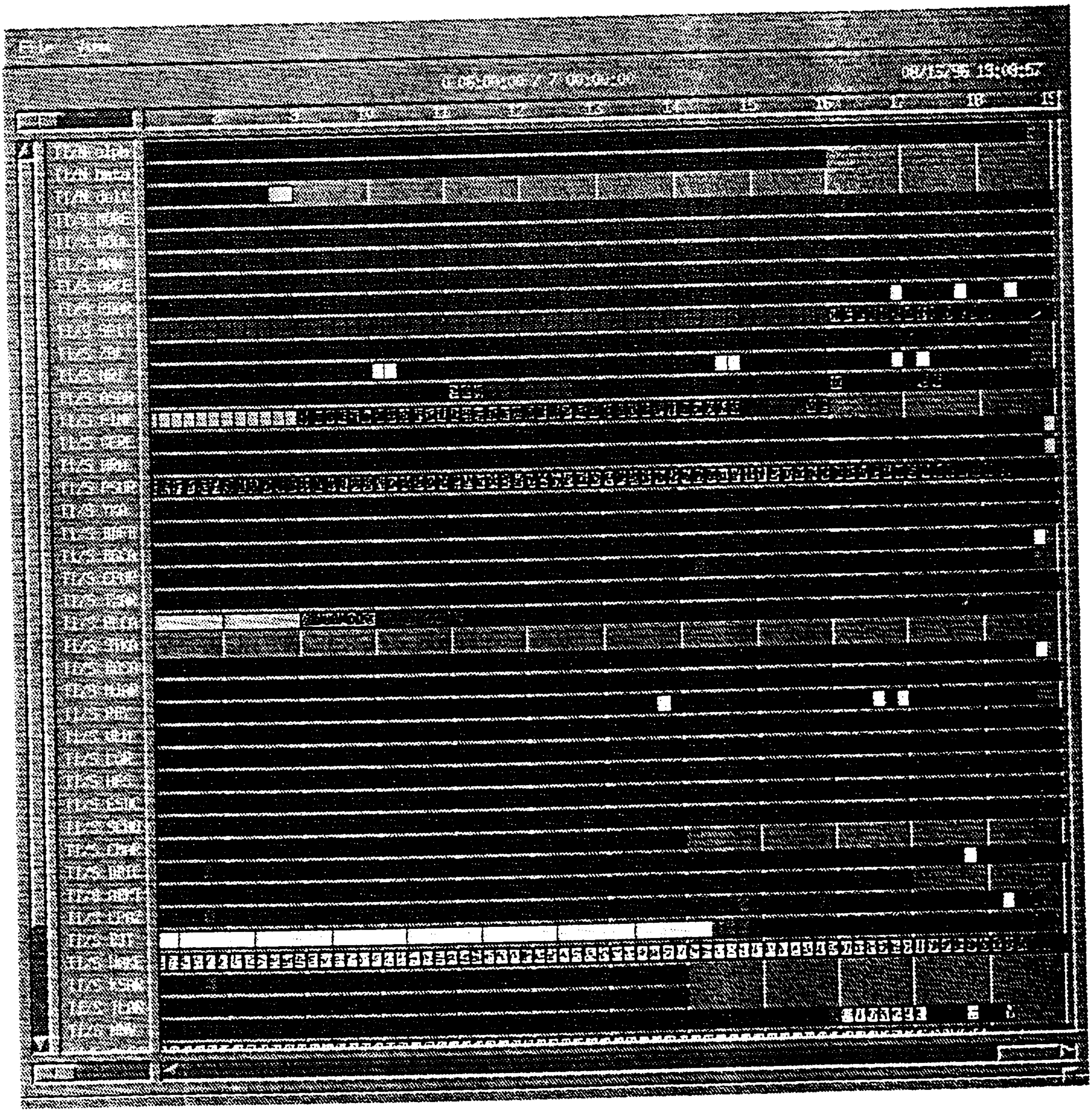


Figure 4.1. Example of the Work Flow diagram. Such diagrams are provided eletronically in near real-time at the EIDC, and give a picture of the status of the EIDC processing.

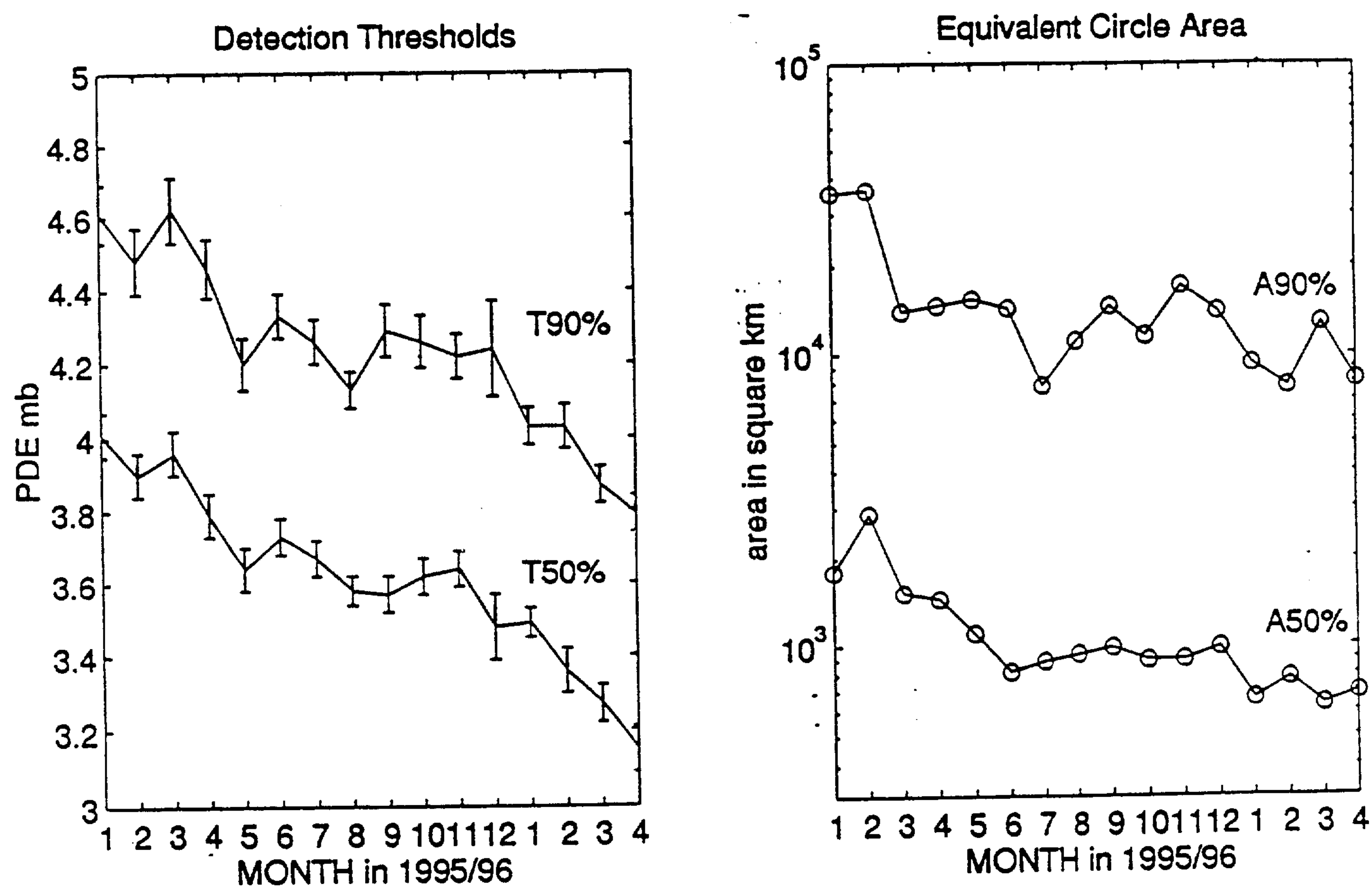
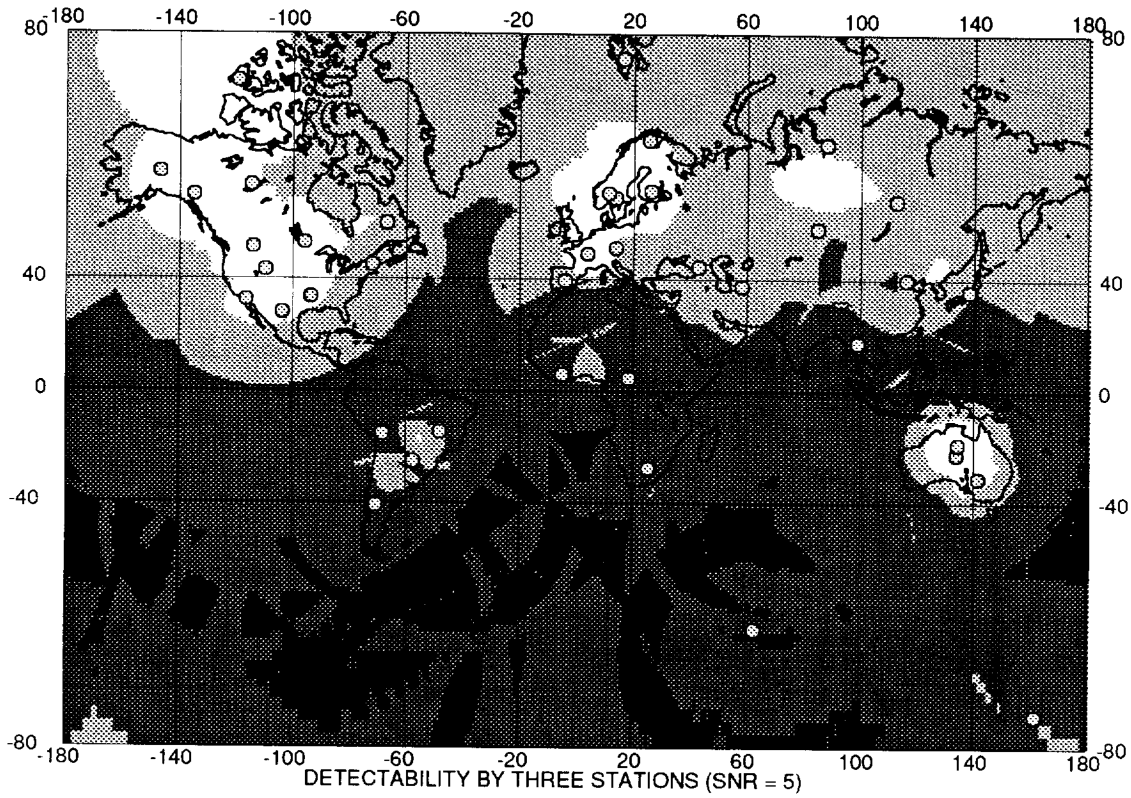


Figure 5.1. Summary of detection performance (left) and location performance (right) on a month-by-month basis during GSETT-3. This figure is based on a comparison with the Preliminary Determination of Epicentres (PDE) bulletin published in the United States, and therefore reflects values averaged over world seismicity as it is reported in the PDE.

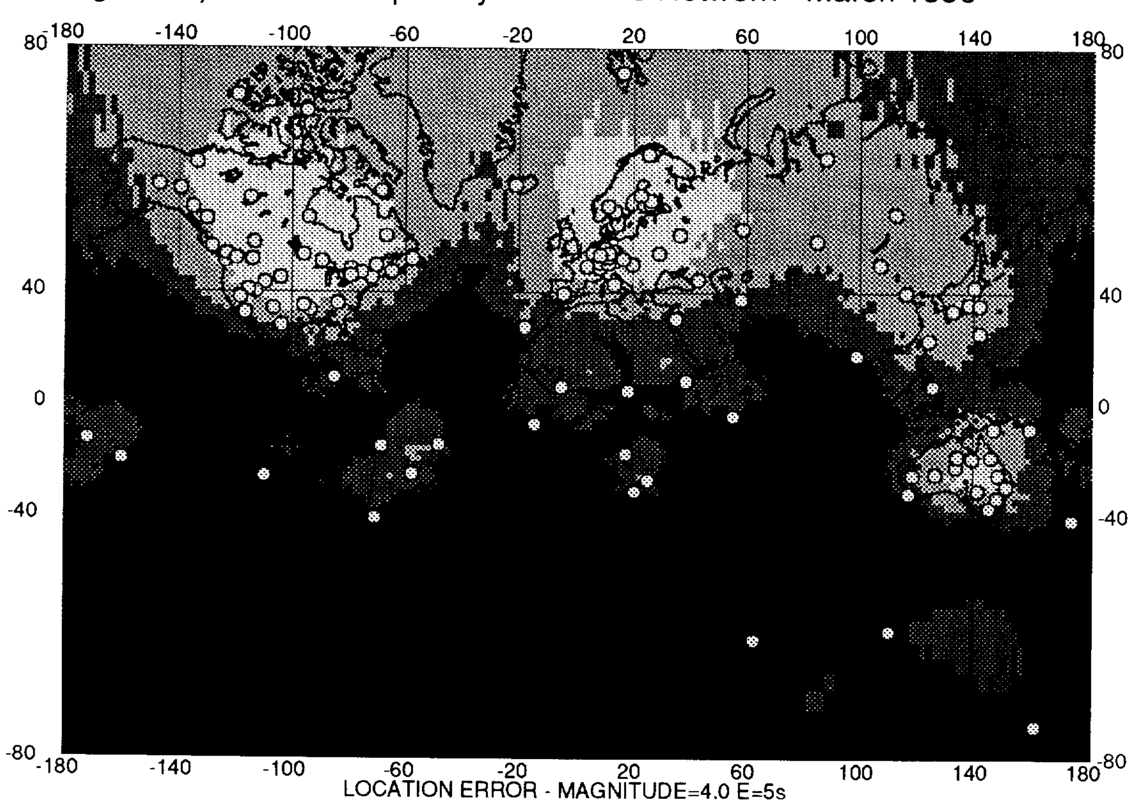
Fig. 5.2 a) Detection Capability: GSETT-3 NETWORK - March 1996



□ mb< 3.5 ▩ 3.5 <mb< 4.0 ■ 4.0 <mb< 4.5 ■ mb> 4.5

◎ Primary Station

Fig. 5.2 b) Location Capability: GSETT-3 Network - March 1996



□ R <17 km ▩ 17 km<R<30 km ▩ 30 km<R<50 km ■ 50 km<R<80 km ■ R >80 km

◎ Primary or Auxiliary Station

ANNEX 1

Table 1a: List of Seismograph Stations Comprising the IMS Primary Network

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
1	Argentina	PLCA Paso Flores	40.7 S	70.6 W	3-C	yes
2	Australia	WRA Warramunga, NT	19.9 S	134.3 E	array	yes
3	Australia	ASAR Alice Springs, NT	23.7 S	133.9 E	array	yes
4	Australia	STKA Stephens Creek, SA	31.9 S	141.6 E	3-C	yes
5	Australia	MAW Mawson, Antarctica	67.6 S	62.9 E	3-C	yes
6	Bolivia	LPAZ La Paz	16.3 S	68.1 W	3-C	yes
7	Brazil	BDFB Brasilia	15.6 S	48.0 W	3-C	yes
8	Canada	ULMC Lac du Bonnet	50.2 N	95.9 W	3-C	yes
9	Canada	YKAC Yellowknife, N.W.T.	62.5 N	114.6 W	array	yes
10	Canada	SCH Schefferville, Quebec	54.8 N	66.8 W	3-C	yes
11	Cenrtal African Republic	BGCA Bangui	05.2 N	18.4 E	3-C	yes
12	China	HAI Hailar	49.3 N	119.7 E	3-C > array	yes
13	China	LZH Lanzhou	36.1 N	103.8 E	3-C > array	no
14	Colombia	XSA El Rosal	04.9 N	74.3 W	3-C	no
15	Côte d'Ivoire	DBIC Dimbroko	06.7 N	04.9 W	3-C	yes
16	Egypt	LXEG Luxor	26.0 N	33.0 E	array	no
17	Finland	FINES Lahti	61.4 N	26.1 E	array	yes
18	France	PPT Tahiti	17.6 S	149.6 W	3-C	no
19	Germany	GEC2 Freyung	48.9 N	13.7 E	array	yes
20	To be determined	To be determined	To be deter-mined	To be deter-mined	To be deter-mined	no
21	Iran (Islamic Republic of)	THR Tehran	35.8 N	51.4 E	3-C	no

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
22	Japan	MJAR Matsushiro	36.5 N	138.2 E	array	yes
23	Kazakstan	MAK Makanchi	46.8 N	82.0 E	array	no
24	Kenya	KMBO Kilimambogo	01.1 S	37.2 E	3-C	no
25	Mongolia	JAVM Javhlant	48.0 N	106.8 E	3-C > array	no
26	Niger	New site	to be deter-mined	to be deter-mined	3-C > array	no
27	Norway	NAO Hamar	60.8 N	10.8 E	array	no
28	Norway	ARAO Karasjok	69.5 N	25.5 E	array	yes
29	Pakistan	PRPK Pari	33.7 N	73.3 E	array	no
30	Paraguay	CPUP Villa Florida	26.3 S	57.3 W	3-C	yes
31	Republic of Korea	KSRS Wonju	37.5 N	127.9 E	array	yes
32	Russian Federation	KBZ Khabaz	43.7 N	42.9 E	3-C	yes
33	Russian Federation	ZAL Zalesovo	53.9 N	84.8 E	3-C > array	yes
34	Russian Federation	NRI Norilsk	69.0 N	88.0 E	3-C	yes
35	Russian Federation	PDY Peleduy	59.6 N	112.6 E	3-C > array	yes
36	Russian Federation	PET Petropavlovsk-Kamchatskiy	53.1 N	157.8 E	3-C > array	no
37	Russian Federation	USK Ussuriisk	44.2 N	132.0 E	3-C > array	no
38	Saudi Arabia	New site	to be deter-mined	to be deter-mined	array	no
39	South Africa	BOSA Boshof	28.6 S	25.6 E	3-C	yes
40	Spain	ESDC Sonseca	39.7 N	04.0 W	array	yes
41	Thailand	CMTO Chiang Mai	18.8 N	99.0 E	array	yes
42	Tunisia	THA Thala	35.6 N	08.7 E	3-C	no

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
43	Turkey	BRTR Belbashi The array is subject to relocation at Keskin	39.9 N	32.8 E	array	no
44	Turkmenistan	GEYT Alibeck	37.9 N	58.2 E	array	yes
45	Ukraine	AKASG Malin	50.4 N	29.12 E	array	no
46	United States of America	LJTX Lajitas, TX	29.3 N	103.7 W	array	yes
47	United States of America	MNV Mina, NV	38.4 N	118.2 W	array	yes
48	United States of America	PIWY Pinedale, WY	42.8 N	109.6 W	array	yes
49	United States of America	ELAK Eielson, AK	64.8 N	146.9 W	array	yes
50	United States of America	VNDA Vanda, Antarctica	77.5 S	161.9 E	3-C	yes

Key:

3-C > array: Indicates that the site could start operations in the International Monitoring System as a three-component station and be upgraded to an array at a later time.

Table 1b: List of Additional Seismograph Stations Participating in the GSETT-3 Primary Network but not Selected for the IMS Network

	State Responsible for Station	Location	Latitude	Longitude	Type
1	Australia	WOOL Woolibar	31.1 S	121.7 E	3-C
2	Canada	WALA Waterton Lakes	49.1 N	113.9 W	3-C
3	Canada	WHY Whitehorse	60.7 N	134.9 W	3-C
4	France	LOR Lormes	47.3 N	3.9 E	3-C
5	Norway	NORES Hamar	60.7 N	11.5 E	array
6	United States	LBNH Lisbon	44.2 N	71.9 W	3-C
7	United States	MIAR Mount Ida	34.5 N	93.6 W	3-C
8	United States	NPO North Pole	64.8 N	146.9 W	3-C

Table 2a: List of Seismograph Stations Comprising the IMS Auxiliary Network

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
1	Argentina	CFA Coronel Fontana	31.6 S	68.2 W	3-C	no
2	Argentina	USHA Ushuaia	55.0 S	68.0 W	3-C	no
3	Armenia	GNI Garni	40.1 N	44.7 E	3-C	no
4	Australia	CTA Charters Towers, QLD	20.1 S	146.3 E	3-C	yes
5	Australia	FITZ Fitzroy Crossing, WA	18.1 S	125.6 E	3-C	yes
6	Australia	NWAO Narrogin, WA	32.9 S	117.2 E	3-C	yes
7	Bangladesh	CHT Chittagong	22.4 N	91.8 E	3-C	no
8	Bolivia	SIV San Ignacio	16.0 S	61.1 W	3-C	no
9	Botswana	LBTB Lobatse	25.0 S	25.6 E	3-C	no
10	Brazil	PTGA Pitinga	0.7 S	60.0 W	3-C	yes
11	Brazil	RGNB Rio Grande do Norte	6.9 S	37.0 W	3-C	no
12	Canada	FRB Iqaluit, N.W.T.	63.7 N	68.5 W	3-C	yes
13	Canada	DLBC Dease Lake, B.C.	58.4 N	130.1 W	3-C	yes
14	Canada	SADO Sadowa, Ont.	44.8 N	79.1 W	3-C	yes
15	Canada	BBB Bella Bella, B.C.	52.2 N	128.1 W	3-C	yes
16	Canada	MBC Mould Bay, N.W.T.	76.2 N	119.4 W	3-C	yes
17	Canada	INK Inuvik, N.W.T.	68.3 N	133.5 W	3-C	yes
18	Chile	RPN Easter Island	27.2 S	109.4 W	3-C	yes
19	Chile	LVC Limon Verde	22.6 S	68.9 W	3-C	no
20	China	BJT Baijiatuan	40.0 N	116.2 E	3-C	yes, as primary
21	China	KMI Kunming	25.2 N	102.8 E	3-C	no

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
22	China	SSE Sheshan	31.1 N	121.2 E	3-C	no
23	China	XAN Xi'an	34.0 N	108.9 E	3-C	no
24	Cook Islands	RAR Rarotonga	21.2 S	159.8 W	3-C	yes
25	Costa Rica	JTS Las Juntas de Aban-gares	10.3 N	85.0 W	3-C	yes
26	Czech Republic	VRAC Vranov	49.3 N	16.6 E	3-C	yes
27	Denmark	SFJ Søndre Strømfjord, Greenland	67.1 N	50.6 W	3-C	yes
28	Djibouti	ATD Arta Tunnel	11.5 N	42.9 E	3-C	no
29	Egypt	KEG Kottamya	29.9 N	31.8 E	3-C	no
30	Ethiopia	FURI Furi	8.9 N	38.7 E	3-C	no
31	Fiji	MSVF Monasavu, Viti Levu	17.8 S	178.1 E	3-C	no
32	France	NOUC Port Laguerre, New Caledonia	22.1 S	166.3 E	3-C	no
33	France	KOG Kourou, French Guiana	5.2 N	52.7 W	3-C	no
34	Gabon	BAMB Bambay	1.7 S	13.6 E	3-C	no
35	Germany/South Africa	VNA SANAE station, Antarctica	71.7 S	2.9 W	3-C	no
36	Greece	IDI Anogia, Crete	35.3 N	24.9 E	3-C	no
37	Guatemala	RDG Rabir	15.1 N	90.5 W	3-C	no
38	Iceland	BORG Borgarnes	64.8 N	21.3 W	3-C	yes
39	To be determined	To be determined	To be deter-mined	To be deter-mined	To be deter-mined	no
40	Indonesia	PACI Cibinong, Jawa Barat	6.5 S	107.0 E	3-C	no
41	Indonesia	JAY Jayapura, Irian Jaya	2.5 S	140.7 E	3-C	no

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
42	Indonesia	SWI Sorong, Irian Jaya	0.9 S	131.3 E	3-C	no
43	Indonesia	PSI Parapat, Sumatera	2.7 N	98.9 E	3-C	no
44	Indonesia	KAPI Kappang Sulawesi Selatan	5.0 S	119.0 E	3-C	no
45	Indonesia	KUG Kupang Nusatenggara Timur	10.2 S	123.6 E	3-C	no
46	Iran (Islamic Republic of)	KRM Kerman	30.3 N	57.1 E	3-C	no
47	Iran (Islamic Republic of)	MSN Masjed-e-Solayman	31.9 N	49.3 E	3-C	no
48	Israel	MBH Eilath	29.8 N	34.9 E	3-C	no
49	Israel	PARD Parod	32.6 N	35.3 E	array	no
50	Italy	ENAS Enna, Sicily	37.5 N	14.3 E	3-C	no
51	Japan	JNU Ohita, Kyushu	33.1 N	130.9 E	3-C	no
52	Japan	JOW Kunigami, Okinawa	26.8 N	128.3 E	3-C	no
53	Japan	JHJ Hachijojima, Izu Islands	33.1 N	139.8 E	3-C	no
54	Japan	JKA Kamikawa-asahi, Hokkaido	44.1 N	142.6 E	3-C	no
55	Japan	JCJ Chichijima, Ogasawara	27.1 N	142.2 E	3-C	no
56	Jordan	-- Ashqof	32.5 N	37.6 E	3-C	no
57	Kazakstan	BRVK Borovoye	53.1 N	70.3 E	array	no
58	Kazakstan	KURK Kurchatov	50.7 N	78.6 E	array	no
59	Kazakstan	AKTO Aktyubinsk	50.4 N	58.0 E	3-C	no
60	Kyrghyzstan	AAK Ala-Archa	42.6 N	74.5 E	3-C	no
61	Madagascar	TAN Antananarivo	18.9 S	47.6 E	3-C	no
62	Mali	KOWA Kowa	14.5 N	4.0 W	3-C	no

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
63	Mexico	TEYM Tepich, Yucatan	20.2 N	88.3 W	3-C	no
64	Mexico	TUVM Tuzandepeti, Veracruz	18.0 N	94.4 W	3-C	no
65	Mexico	LPBM La Paz Baja California Sur	24.2 N	110.2 W	3-C	no
66	Morocco	MDT Midelt	32.8 N	4.6 W	3-C	no
67	Namibia	TSUM Tsumeb	19.1 S	17.4 E	3-C	yes
68	Nepal	EVN Everest	28.0 N	86.8 E	3-C	no
69	New Zealand	EWZ Erewhon, South Island	43.5 S	170.9 E	3-C	no
70	New Zealand	RAO Raoul Island	29.2 S	177.9 W	3-C	no
71	New Zealand	URZ Urewera, North Island	38.3 S	177.1 E	3-C	no
72	Norway	SPITS Spitsbergen	78.2 N	16.4 E	array	yes, as primary
73	Norway	JMI Jan Mayen	70.9 N	8.7 W	3-C	no
74	Oman	WSAR Wadi Sarin	23.0 N	58.0 E	3-C	no
75	Papua New Guinea	PMG Port Moresby	9.4 S	147.2 E	3-C	yes
76	Papua New Guinea	BIAL Bialla	5.3 S	151.1 E	3-C	no
77	Peru	CAJP Cajamarca	7.0 S	78.0 W	3-C	no
78	Peru	NNA Nana	12.0 S	76.8 W	3-C	yes
79	Philippines	DAV Davao, Mindanao	7.1 N	125.6 E	3-C	yes
80	Philippines	TGY Tagaytay, Luzon	14.1 N	120.9 E	3-C	no
81	Romania	MLR Muntele Rosu	45.5 N	25.9 E	3-C	no
82	Russian Federation	KIRV Kirov	58.6 N	49.4 E	3-C	no
83	Russian Federation	KIVO Kislovodsk	44.0 N	42.7 E	array	yes
84	Russian Federation	OBN Obninsk	55.1 N	36.6 E	3-C	yes

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
85	Russian Federation	ARU Arti	56.4 N	58.6 E	3-C	yes
86	Russian Federation	SEY Seimchan	62.9 N	152.4 E	3-C	no
87	Russian Federation	TLY Talaya	51.7 N	103.6 E	3-C	no
88	Russian Federation	YAK Yakutsk	62.0 N	129.7 E	3-C	no
89	Russian Federation	URG Urgal	51.1 N	132.3 E	3-C	no
90	Russian Federation	BIL Bilibino	68.0 N	166.4 E	3-C	no
91	Russian Federation	TIXI Tiksi	71.6 N	128.9 E	3-C	no
92	Russian Federation	YSS Yuzhno-Sakhalinsk	47.0 N	142.8 E	3-C	no
93	Russian Federation	MA2 Magadan	59.6 N	150.8 E	3-C	no
94	Russian Federation	ZIL Zilim	53.9 N	57.0 E	3-C	no
95	Samoa	AFI Afiamalu	13.9 S	171.8 W	3-C	yes
96	Saudi Arabia	RAYN Ar Rayn	23.6 N	45.6 E	3-C	no
97	Senegal	MBO Mbour	14.4 N	17.0 W	3-C	no
98	Solomon Islands	HNR Honiara, Guadalcanal	9.4 S	160.0 E	3-C	yes
99	South Africa	SUR Sutherland	32.4 S	20.8 E	3-C	yes
100	Sri Lanka	COC Colombo	6.9 N	79.9 E	3-C	no
101	Sweden	HFS Hagfors	60.1 N	13.7 E	array	yes, as primary
102	Switzerland	DAVOS Davos	46.8 N	9.8 E	3-C	yes
103	Uganda	MBRU M'Barara	0.4 S	30.4 E	3-C	no
104	United Kingdom	EKA Eskdalemuir	55.3 N	3.2 W	array	yes
105	United States of America	GUMO Guam, Marianas Islands	13.6 N	144.9 E	3-C	no
106	United States of America	PMSA Palmer Station Antarctica	64.8 S	64.1 W	3-C	no

	State Responsible for Station	Location	Latitude	Longitude	Type	In GSETT-3 August 1996
107	United States of America	TKL Tuckaleechee Caverns, TN	35.7 N	83.8 W	3-C	yes
108	United States of America	PFCA Pinon Flat, CA	33.6 N	116.5 W	3-C	yes, as primary
109	United States of America	YBH Yreka, CA	41.7 N	122.7 W	3-C	no
110	United States of America	KDC Kodiak Island, AK	57.8 N	152.5 W	3-C	no
111	United States of America	ALQ Albuquerque, NM	35.0 N	106.5 W	3-C	yes
112	United States of America	ATTU Attu Island, AK	52.8 N	172.7 E	3-C	no
113	United States of America	ELK Elko, NV	40.7 N	115.2 W	3-C	yes
114	United States of America	SPA South Pole, Antarctica	90.0 S	--	3-C	no
115	United States of America	NEW Newport, WA	48.3 N	117.1 W	3-C	yes
116	United States of America	SJG San Juan, PR	18.1 N	66.2 W	3-C	no
117	Venezuela	SDV Santo Domingo	8.9 N	70.6 W	3-C	yes
118	Venezuela	PCRV Puerto la Cruz	10.2 N	64.6 W	3-C	no
119	Zambia	LSZ Lusaka	15.3 S	28.2 E	3-C	yes
120	Zimbabwe	BUL Bulawayo	to be advised	to be advised	3-C	no

Table 2b: List of Additional Seismograph Stations Participating in the GSETT-3 Auxiliary Network but not Selected for the IMS Network

	State Responsible for Station	Location	Latitude	Longitude	Type
1	Australia	ARMA Armidale	30.4 S	151.6 E	3-c
2	Australia	CSY Casey	66.3 S	110.5 E	1-C
3	Australia	FORT Forrest	30.8 S	128.1 E	1-C
4	Australia	MEEK Meekatharra	26.6 S	118.5 E	1-C
5	Australia	QIS Mount Isa	20.6 S	139.6 E	1-C
6	Australia	RMQ Roma	26.5 S	148.8 E	1-C
7	Australia	TOO Toolangi	37.6 S	145.5 E	3-C
8	Australia	WARB Warburtan	26.2 S	126.6 E	3-C
9	Australia	YOU Young	34.3 S	148.4 E	3-C
10	Bulgaria	VTS Vitosha	42.6 N	23.2 E	3-C
11	Canada	LMN Caledonia Mtn.	45.9 N	64.8 W	3-C
12	Canada	DAWY Dawson City	64.1 N	139.4 W	3-C
13	Canada	DRLN Deer Lake	49.3 N	57.5 W	3-C
14	Canada	EDM Edmonton	53.2 N	113.4 W	3-C
15	Canada	EEO Eldee	46.6 N	79.1 W	1-C
16	Canada	FCC Fort Churchill	58.8 N	94.1 W	3-C
17	Canada	GAC Glen Almond	45.7 N	75.5 W	3-C
18	Canada	LMQ La Malbaie	47.5 N	70.3 W	3-C
19	Canada	PGC Pac. Geoscience	48.7 N	123.5 W	3-C
20	Canada	PMB Pemberton	50.5 N	123.1 W	3-C
21	Canada	PNT Penticton	49.3 N	119.6 W	3-C

	State Responsible for Station	Location	Latitude	Longitude	Type
22	Canada	RES Resolute Bay	74.7 N	94.9 W	3-C
23	Canada	TBO Thunder Bay	48.6 N	89.4W	1-C
24	Ethiopia	AAE Addis Ababa	9.0 N	38.8 E	3-C
25	Finland	KAF Kangasniemi	62.1 N	26.3 E	3-C
26	Finland	VAF Ylistaro	63.0 N	22.7 E	3-C
27	Germany	BRG Berggiesshübel	50.9 N	13.9 E	3-C
28	Germany	BFO Black Forest	48.3 N	8.3 E	3-C
29	Germany	BUG Bochum	51.4 N	7.3 E	3-C
30	Germany	CLZ Clausthal-Zellerfeld	51.8 N	10.4 E	3-C
31	Germany	CLL Collm	51.3 N	13.0 E	3-C
32	Germany	FUR Fürstenfeldbruck	48.2 N	11.3 E	3-C
33	Germany	GRFO Gräfenberg	49.7 N	11.2 E	3-C
34	Germany	MOX Moxa	50.6 N	11.6 E	3-C
35	Germany	TNS Taunus	50.2 N	8.4 E	3-C
36	Hungary	PSZ Piszkes	47.9 N	19.9 E	3-C
37	Israel	BGIO Bar Giyora	31.7 N	35.1 E	3-C
38	Italy	AQU L'Aquila	42.4 N	13.4 E	3-C
39	Italy	VSL Villasalto	39.5 N	9.4 E	3-C
40	Japan	OGS Chichijima	27.1 N	142.2 E	3-C
41	Japan	ISG Ishigakijima	24.4 N	124.2 E	3-C
42	Japan	KKJ Kaminokuni	41.8 N	140.2 E	3-C
43	Japan	SHK Shiraki	34.5 N	132.7 E	3-C
44	Japan	TSK Tsukuba	36.2 N	140.1 E	3-C

	State Responsible for Station	Location	Latitude	Longitude	Type
45	Mongolia	ULN Ulaan-Baatar	47.5 N	107.0 E	3-C
46	Netherlands	HGN Heimansgroeve	50.8 N	5.9 E	3-C
47	New Zealand	SNZO South Karori	44.3 S	174.7 E	3-C
48	Pakistan	NIL Nilore	33.7 N	73.3 E	3-C
49	Seychelles	MSEY Mahe	4.6 S	55.5 E	3-C
50	Spain	PAB San Pablo de los Montes	39.5 N	4.3 W	3-C
51	Spain	TBT Taburiente	28.7 N	17.9 W	3-C
52	Switzerland	APL Alpnach	47.0 N	8.2E	3-C
53	Ukraine	KIEV Kiev	50.7 N	29.2 E	3-C
54	United Kingdom	WOL Wolverton	51.3 N	1.2 W	3-C
55	United Kingdom	ASCN Ascension Island	8.0 S	14.4 W	3-C
56	United States	RSSD Black Hills	44.1 N	104.0 W	3-C
57	United States	BLA Blacksburg	37.2 N	80.4 W	3-C
58	United States	DUG Dugway	40.2 N	112.8 W	3-C
59	United States	EYMN Ely	47.9 N	91.5 W	3-C
60	United States	TUC Tucson	32.3 N	110.8 W	3-C
61	United States	TUL Tulsa	35.9 N	95.8 W	3-C