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6.1 Seismic Event Location Calibration

Report from the IDC Technical Experts Meeting in Oslo, Norway 4-9 May 2003

6.1.1 Introduction

The International Data Centre (IDC) Technical Experts Group on Seismic Event Location held its fifth annual meeting in Oslo, Norway on 4-9 May 2003. The purpose of the meeting was to support the ongoing calibration efforts of the IDC and in particular to review progress toward developing regionalized travel times to improve the quality of location estimates of seismic events reported in the IDC bulletins.

Sixty technical experts, coming from ten signatory countries and the Provisional Technical Secretariat, participated in the meeting. Dr. Frode Ringdal of Norway chaired the meeting.

6.1.2 Background and technical objectives

Working Group B has repeatedly encouraged States Signatories to support the location improvement efforts by supplying relevant location calibration information for their own territories as well as for other regions where they have such information available. The following types of calibration information were proposed in the document CTBT/WGB-6/CRP.26:

- Precise information on location, depth, and origin time of previous nuclear explosions or large chemical explosions
- Similar information on other seismic events that have been located by regional networks with sufficient precision
- Data as appropriate on seismic travel-time models
- Any other information (e.g., geologic or tectonic maps) that would be useful
- Ground truth data from chemical explosions.

At its first meeting in January 1999, the IDC Technical Experts Group on Seismic Event Location developed plans and recommendations for a global calibration program, and presented its report to Working Group B in February 1999 (CTBT/WGB/TL-2/18). This work was reviewed and updated during subsequent meetings of the Experts Group in March 2000, April 2001 and April 2002, and the results were subsequently presented to Working Group B (CTBT/WGB/TL-2/49, CTBT/WGB/TL-2/61 and CTBT/WGB/TL-2/70). The fifth meeting of the Experts Group (4-9 May 2003), reported in this paper, had the following objectives:

- To report on and review progress of ongoing research work on location calibration at national and international levels, including calibration consortia and PTS Calibration Programme Phase 1 contracts
- To discuss the development of event validation sets, using various categories of available "Ground Truth" location information

- To review proposals for station-specific regional location corrections, with particular emphasis on IMS stations in North America, Europe, North Africa, Asia and Australia
- To compare sets of such corrections, including appropriate model errors, and consider their value for incorporation into the operational IDC software
- To develop a plan for extensions and improvements of this regional correction data base, to be incorporated into IDC software in the future
- To review progress in the general recommendations from the previous meetings, and make adjustments and updates to these recommendations as required.
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The primary task of the meeting was to assess the status and availability of regional calibration information for the geographical areas being considered, to plan for implementing such calibration information at the IDC as well as discuss the need for future research and development.

6.1.3 Technical Issues

Presentations during the meeting

A number of papers relating to the collection, application and validation of calibration information were presented by participants. Models for regionalization on a global basis were presented and discussed. Specific presentations were made by several experts describing regional velocity models and calibration data for the geographic regions being considered initially. Information was provided about the current CTBTO Calibration Programme. Progress was reported at the workshop by CTBTO sponsored contractors, by the U.S sponsored consortia which by the time of the meeting had completed their three-year calibration efforts, and by several other research groups.

As during previous meetings, it was noted that for some regions, information was incomplete or lacking, and the use of default “generic” velocity models for various tectonic regions was discussed in some detail. Valuable new data on ground truth (GT) information for seismic events was presented. These data will be organized and made available to the IDC and interested States Signatories. Countries were encouraged to continue to provide relevant calibration data to the IDC for the purpose of developing accurate seismic travel-time curves for various geographical regions, with the goal to achieve ultimately full global coverage.

Reports were presented on a number of modelling studies, some of which showed significant improvement in location precision when applied to test sets of GT seismic events. Three-dimensional models were introduced for several regions and were found to provide considerable improvements in location accuracy compared to standard (IASPEI-91) models.

Techniques for improved regional processing using single arrays or 3-component stations as well as sparse seismic networks were presented and discussed. The application of special location and depth estimation techniques was also addressed.

Working Group Discussions

Three Working Groups were established to discuss technical issues in detail during the workshop:

Working Group 1: Calibration of Northern Eurasia and East Asia

Working Group 2: Calibration of Southwestern Asia and the African/Mediterranean area

Working Group 3: Methods for detection and location

The first two Working Groups were given a mandate with a list of specific questions addressing the following topics:

Topic 1: Validation and Implementation of Regional Calibration Information

Topic 2: Collection of Regional Calibration Information

Topic 3: Application of Regional Calibration Information

Topic 4: Future work of the Experts Group

The third working group was given a special mandate to assess the quality of existing processing methods and to identify areas in which further research work is required.

The results of the Working Groups were presented and discussed in a plenary session. In some cases, previous recommendations were reiterated or amplified. These presentations and discussions provided the basis for the summary recommendations presented below. The detailed reports of these Working Groups are available on request from the Chairman of the Experts Group, Dr. Frode Ringdal, Norway.

6.1.4 Results and recommendations

Status of the calibration effort

Participants reported considerable progress in GT event data collection, GT criteria, and regional calibration. GT event lists have significantly increased over the last year. New GT category criteria to select candidate GT events proposed in the previous meetings have been applied and evaluated. Regional calibration has demonstrated reduced bias (absolute errors) and decreased uncertainty (smaller error ellipses) in accordance with the goals of the IMS calibration effort.

Preliminary regional corrections have been implemented at the IDC for IMS stations in northwestern Europe and northern America. The expert group recommended that the IDC continue their efforts to further develop and implement such corrections for the priority regions.

Northern Eurasia and East Asia

For this region, large collections of calibration data/information are becoming available from several research groups, including IDC contractors and the US-sponsored Group 1 consortia. The IDC should make plans to acquire, archive and evaluate these data, including associated bulletin data and available waveforms, within a globally consistent database. Specific data sets of GT events include, inter alia: (1) Soviet explosion database and associated bulletin data, (2) chemical calibration explosions conducted at Semipalatinsk, (3) Lop Nor nuclear explosions for which GT1 locations have been established and with regional recordings; (3) nuclear explosions during May 1998 at the Indian and Pakistani test sites; (4) clusters of GT5 events within China, Taiwan (China), Japan, Republic of Korea, and Kyrgyzstan that were established by the

Columbia University consortium; (5) clusters of GT5-10 events established by R. Engdahl for India, Tajikistan, Georgia, and Russia.

Multiple sets of SSSCs are now available for IMS stations in this region that have been shown to significantly improve location performance. It is strongly recommended that the IDC develop an initiative program with explicit plans to proactively acquire, evaluate, and install appropriate SSSCs in the routine IDC processing. This task should be the highest priority for the IDC in the area of location performance enhancement in the coming year. As an initial step in this process, the IDC should evaluate the version of SSSCs that have already been delivered to the IDC by the Russian Federation – United States Joint Calibration Programme, and implement them in the routine processing at the IDC.

Southwestern Asia and the African/Mediterranean area

For this region as well, significant progress in the last year was reported. Among the IDC contractors, Cornell University (US) and GII (Israel) have delivered GT data, velocity models, and SSSCs to the IDC/PTS for the Middle East. NORSAR (Norway) and IIEES (Iran) will deliver, by the end of 2003, GT data, models, and SSSCs for the region of Iran. The US-sponsored Group 2 consortium will soon deliver to the US DTRA/DoD a compilation of over 1900 GT events, several 3D velocity models, and computed sets of SSSCs for the region. There now exist one or more regional SSSCs for all IMS stations within the region. There now exists a body of GT events and arrivals suitable for evaluation of proposed SSSCs for the entire region.

Reports by the Group 2 Consortium on the performance of model-based teleseismic P-wave SSSCs are very encouraging and the expert group recommends that these calibrations should be considered as a next logical step for calibrating travel-times.

The existing available GT0-5 data collections will most probably constitute the bulk of the available events in this region for the near future. Efforts must continue to collect events to establish better coverage in North Africa and the Middle East. However, the existing sets of GT0-5 events will form the core of the required validation data sets.

The expert group acknowledges that GT data in this region is sparse and formal and informal data collection efforts must continue. Data for the region is still largely limited to GT5-GT10 earthquakes. The criteria for assigning GT level of location accuracy must be unambiguously documented.

Specific recommendations

Validation and Implementation of Regional Corrections for IDC

- The revised location performance metrics defined in the previous meeting of the experts group (CTBT/WGB/TL-2/70) are adequate, but consideration is needed as to which data sets to apply them to, preferably using a sparse IMS network or with suitable surrogate stations. The metrics should be considered in the context of magnitude and the number and azimuthal distribution of reporting stations.
- Validation data sets of GT events should be established at the IDC for the systematic evaluation of various sets of SSSCs that are now becoming available for common stations. Such validation data sets should consist of the highest quality events with well-balanced geographic sampling to provide objective assessment of SSSC performance.

- Validation data sets should be based on GT events of various categories, and should contain all relevant information (metadata) about the events in the data base. The data should be carefully quality controlled by the organization providing the data. Information on the quality control of origins and arrival times should be provided to the IDC along with the data.
- The Expert Group re-emphasized the need for a formal procedure for validation. In addition, there should be standards for implementation and periodic checking of performance.
- Preliminary results indicate that implementation of teleseismic travel time corrections may also be significant for improving location estimates. Such teleseismic corrections should be consistent with regional corrections.

Testing and Evaluation of Regional Calibration Information

- The IDC should test and evaluate the performance of various sets of SSSCs as an explicit function of the GT quality of available calibration data, with highest emphasis on GT0-2 explosions, where available.
- As a longer-term goal, the IDC should establish a continuing program to systematically and periodically enhance SSSCs using improved earth models and new ground-truth data as they become available and work towards a truly global coverage of the calibration programme.
- Definition of onset times for secondary regional phases is an important and difficult problem. Additional studies, processing methods, and analyst training procedures should be encouraged to enhance the utility of such phases for location estimation.
- Several new algorithms have been implemented and/or utilized in the regional calibration work by various groups that should be considered for evaluation and potential use at the IDC. Such algorithms include single and multiple event location codes (e.g., JHD, HDC, double-difference, grid search), kriging and tomographic codes for use in estimation of SSSCs, cross-correlation techniques with potential to improve phase onset times, and 3D raytracing codes. The IDC should prepare an inventory of such algorithms that are useful to their mission and prioritise plans for future evaluation on the testbed. Research groups which are using these algorithms are encouraged to provide the IDC with detailed information and/or test versions of their computer codes together with any available documentation.
- Researchers are encouraged to consider related topics and in particular the location problem in the presence of correlated errors and deviations from Gaussian statistics.

Automatic Processing Techniques

Single-array processing

Array tuning studies have shown that it is difficult to obtain general rules for improving the array processing. Different arrays have shown very different background noise conditions and signal characteristics such that general-purpose algorithms/setups are not necessarily applicable. Noise conditions are often time varying (seasonal and diurnal variations). Corrections are often frequency dependent. Use of fixed time windows and frequency bands have shown to improve stability of f-k estimates.

Future work should include investigating the possibility of multiple f-k measurements in fixed time and frequency windows. It would also be appropriate to take a new look at noise and/or

signal adaptive processes. National contributions to array/station tuning at the IDC are encouraged.

Three-component processing

The experts believe that there is more room for improvements in the data processing for 3C stations than for arrays. Many ideas have been forwarded (polarization analysis, 2C detectors, etc.), but the algorithms need to be developed and tested in an operational environment. Rotation of components before picking S-onsets should be tested. For 3-component stations, unlike arrays, there is no data redundancy, and consequently quality control and data conditioning is more difficult. It is a rather complex task to retrieve reliable phase identification for a single detection at a 3C station, so several detections may need to be analyzed in context to reliably identify secondary phases.

Screening of recurring mine explosions

Adequate GT information (at least for several events for selected mines) is needed to attempt to develop a master event approach for the purpose of automatic screening of recurring mine explosions. Some promising results were reported during the workshop. A useful approach might be to aim at statements such as:

- This event is likely attributed to mine X, at a given confidence level.
- It is located within an estimated distance of Y km from the mine.
- It has certain characteristics (specified) that makes it consistent with recordings from known mining explosions in the same area.

Detection and phase association algorithms

Progress in alternative detection algorithms was noted. The experts consider as particularly promising Fisher-detectors, correlation-based techniques and noise-adaptive detection procedures. 3-C algorithms such as polarization detectors are also recommended for further evaluation. The detection of secondary phases may be aided by algorithms, which lower the required signal-to-noise threshold for detection for a certain time interval after a P-detection. Additionally, an automatic search for secondary phases could be initiated each time a P-phase is detected. The current phase association technique employed at the IDC is considered quite efficient, but requires additional tuning.

Methods for confident detection and identification of depth phases remain an important problem, and research in this area should continue. Focused discussion of selected topics such as depth estimation in the full assembly of experts is encouraged.

Data quality control and data conditioning

There is a need for improved ways to detect and handle problems with the data, such as spikes, outages, spurious noise bursts and timing problems. Improved quality control and data conditioning routines are needed. Wrong polarity and sensor orientation also sometimes cause problems. Errors must be tracked and written to a database, as part of an improved QC system.

Future work

The Experts Group should continue to review and evaluate additional GT data sets, improved models and calibration terms for IMS stations, as they become available, and should provide recommendations regarding their potential use at the IDC.

The expert group recommends that the next Location Workshop focus on a program of evaluations by NDCs and experts of existing SSSCs with the goal of making further recommendations for sets or subsets of calibrations to be installed at the IDC for routine processing. A future workshop should also address issues relevant to automatic processing method developments.

Evaluation of the regional corrections

The expert group recommends that an experimental evaluation of SSSCs should now proceed with the goal of selecting sets or subsets of proposed SSSCs for installation into routine IDC processing. It is proposed that the next Location Workshop focus on evaluation results. To facilitate the evaluation, the IDC could perform offline all available GT event relocations with available sets of SSSCs and publish the resulting bulletins with supporting database tables. The IDC could consider four (at a minimum) sets of SSSCs (with reference to the consortia efforts and the PTS calibration programme, these may be denoted "Group 2", "Group 1A", "Group 1B", and PTS, respectively). At the same time, the IDC could perform offline relocation of between 3 and 12 months of the IDC REB with available sets of SSSCs and publish the resulting bulletins with supporting database tables. NDCs, experts, and the IDC could then evaluate the published results and report at the next Location Workshop.

Calibration explosions

The expert group recommended that the PTS calibration programme be continued and if possible expanded in the future. The collection of data should expand into those areas which have not been covered so far (e.g. Africa, South America and the oceanic areas). One important aspect would be to initiate international co-operation in carrying out a series of large chemical calibration explosions on land and in water. This would allow reliable regional calibration information to be collected in regions, which are not well covered at the present time, and to validate existing calibration corrections.

Of particular importance would be to detonate such calibration explosions during the time periods of future integrated system performance testing of the international monitoring system. This would be valuable in enabling a comparison between the locations calculated by the IDC and the true event locations.

The experts also emphasized the close relation between the event calibration programme and the requirements specified in the Treaty for area to be covered by possible future on-site inspections (maximum area 1000 square kilometers with a maximum linear extent of 50 km). Improving the accuracy of event location as well as obtaining realistic location error ellipses are important in this regard. The experts noted that the accuracy of locations in the IDC bulletins will need to be improved in order to provide the high-quality locations that are required as input for such possible on-site inspections.

Collection of Ground Truth (GT) events

Collection of a set of GT events will continue to be a priority with emphasis on precise hypocenters and origin times and a good global geographic coverage. The GT events should be chosen so as to keep usage of surrogate (non-IMS) stations to a minimum. GT events should be recorded regionally and should comprise a range of magnitudes.

Need for wider participation

The experts re-iterated their concern with the unfortunate low level of participation in calibration activities in under-represented areas such as Africa. The IDC and concerned states may wish to engage in programs to encourage participation in such areas. Such activities might include professional exchanges of personnel with groups actively engaged in calibration to promote exchange of data and expertise. In recognition of the importance of aftershock surveys in the generation of valuable GT events, other activities might include support of temporary aftershock recordings (instruments and personnel) and a clearing-house to collect aftershock data and maintain an open database of aftershock metadata that can be used for calibration and GT event collection.

These recommendations will be considered before the next meeting of the Experts Group.

Frode Ringdal