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Technical Summary

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6.1 Seismic Event Location Calibration

Report from the IDC Technical Experts Meeting in Oslo, Norway 23-27 April 2001

6.1.1 Introduction

The International Data Centre (IDC) Technical Experts Group on Seismic Event Location held its third annual meeting in Oslo, Norway on 23-27 April 2001. The purpose of the meeting was to support the ongoing calibration effort 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-five technical experts, coming from fourteen signatory countries and the Provisional Technical Secretariat, participated in the meeting. In accordance with previous recommendations, the focus of the discussions was on the following geographical regions: North America, Eurasia, Northern Africa and Australia. 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 the second meeting of the Experts Group in March 2000, and the results were presented to Working Group B in May 2000 (CTBT/WGB/TL-2/49). The third meeting of the Experts Group (23-27 April 2001) had the following objectives:

- To review proposals for detailed station-specific regional corrections to be applied for IMS stations in North America, Europe, North Africa, Asia and Australia
- To recommend a set of such corrections, including appropriate model errors, for incorporation into the next release of the IDC software
- To review progress in the general recommendations from the first and second meetings, and make adjustments and updates to these recommendations as required.

The primary task of the meeting was to assess the status and availability of such calibration information for the regions being considered, and to plan for implementing regional location calibration at the IDC, both for the next release of the IDC applications software and for implementation in the longer term. Information was provided about the CTBTO Calibration Programme initiated in 2000. Most of the scientific organizations to which contracts were awarded by CTBTO in 2000 participated at the workshop with presentations on their planned work and initial achievements.

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 general geographic regions being considered initially.

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, the prototype IDC and interested States Signatories. Countries were encouraged to continue to provide relevant calibration data for the purpose of developing accurate seismic travel-time curves for various geographical regions.

Reports were presented on a number of modelling studies, some of which showed significant improvement in location precision when applied to test sets of seismic events. For example, one-dimensional regional Pn, Pg, Sn, and Lg travel time curves were shown to provide improvements for the Baltic shield and the Barents region. Three-dimensional models were introduced for North America and Western Russia and were found to provide considerable improvements in location accuracy compared to standard (IASPEI-91) models.

Techniques for improved regional processing using sparse seismic networks as well as improved azimuth determination for regional arrays were presented and discussed. The application of special location techniques was also addressed.

Working Group Discussions

Three Working Groups, each focusing on specific regions of the world, were established to discuss technical issues in detail during the workshop:

Working Group 1: Northern Eurasia and East Asia

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

Working Group 3: North and South America, Australia

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

Topic 1: Implementing regional corrections into the IDC operating software

Topic 2: Collection of Regional Calibration Information

Topic 3: Application of Regional Calibration Information

Topic 4: Validation of Regional Calibration Information

Topic 5: Future work of the Experts Group

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 recommendations presented below.

6.1.4 Results and recommendations

Main conclusions

The experts note with satisfaction that the work on implementing regional corrections is progressing well, and that such corrections now have been implemented for IMS stations in north-western Eurasia and northern America. Progress was reported at the workshop by U.S sponsored consortia, by CTBTO sponsored contractors and by several other research groups.

During the course of the experts' work the importance of *validation* of ground truth data has become increasingly clear. Validation is a far more complex and time-consuming undertaking than initially expected. The experts recommend that a systematic procedure be established for the validation of ground truth data, and that this procedure be rigorously carried out before new ground truth data is accepted into the operating software for calibration usage.

The experts consider it essential that States Signatories continue to contribute actively to the calibration program by supplying relevant location calibration information for their own territories as well as for other regions where they have such information available. The relevant location information is defined in CTBT/WGB-6/CRP.26.

The experts consider that Confidence-Building Measures, especially chemical calibration explosions, are important to regional calibration, and encourage States Signatories to carry out additional such explosions or to take advantage of such explosions conducted for other purposes. The experts reiterate their recommendation that the PTS solicit from States Signatories waveform data recorded on national seismic stations of such calibration explosions.

The experts were informed about new provisions included in the Preparatory Commission Report of November 2000 on access to IMS data and IDC products by contracted scientific research organization. Still, the experts expressed concern about the current restrictions on obtaining IMS data and IDC products, and recommended that the IDC make openly available to the scientists involved in the IDC location calibration effort all of the waveform data and associated IDC products that are needed in order to successfully carry out the calibration program.

A continued full utilization of the resources of the prototype IDC, which is operated by the Center for Monitoring Research (CMR) in Arlington, Virginia, USA, will be important for future IDC development. The experts recommend that the prototype IDC should continue to act as a resource facility for the international location calibration effort, thus compiling, organizing and making openly available to the scientific community all relevant information on calibration events, travel-time curves, geological/ geophysical information and other ground truth data.

The validated information collected at the prototype IDC will be transferred to the IDC as it becomes available. The responsibility for these calibration data and the associated processing software will be transferred from the prototype IDC to the IDC on a stage-by-stage basis.

Detailed results and recommendations

Topic 1: Implementing regional corrections for the IDC operating software

Region 1

For Region 1 (Northern Eurasia and East Asia) source-specific station correction (SSSC) have previously been implemented for IMS stations in Fennoscandia. It is anticipated that a variety of SSSC estimates for many additional IMS stations in this region will be available for potential inclusion in updates to Release 3 of the IDC software, although full validation studies are not expected to be completed for another two years. These will include separate estimates from the two U.S. sponsored calibration consortia, as well as estimates from various Russian and CTBTO sponsored studies. The results of all these studies should be made available to the research community. An effort should be initiated in the coming year to define how such multiple estimates of corrections for specific stations are to be systematically compared and evaluated. The existing evaluation process used by the Configuration Control Board is not considered optimal for this purpose.

Region 2

For Region 2 (Southwestern Asia and the African/Mediterranean area) no travel time corrections are currently available. Progress was reported at the workshop by U.S. sponsored consortia at the large scale and at the smaller scale by CTBTO sponsored and other research groups. Preliminary regional travel time corrections will be available in 2002 and revised corrections will follow in 2003 as an update to the current operating software. The largest deficiencies in the region at this stage are a lack of well located validation events to demonstrate unambiguously that the proposed corrections make significant improvements in location across the region, and it is recommended that future efforts focus upon this problem. Areas of particular difficulty include the seismically active areas of North Africa along the Mediterranean and the East African Rift.

Region 3

For Region 3 (North America, Australia) there have been some recent developments. SSSCs based on 3-D modelling for all IMS stations in Canada and the USA have been generated, tested, validated, and implemented. They are in an updated version of Release 3 currently at the IDC. There are, however, currently no corrections for stations in Mexico. Corrections for IMS stations in Australia based on research sponsored by CTBTO are expected in 1-2 years. Validation is believed to be good for the U.S. stations and spotty elsewhere (there is great variability in quality).

General

The Experts Group remains concerned that there is lack of transparency in the IDC bulletin products that reflect the corrections that are being applied to travel times, azimuths, and slownesses for location purposes. The experts strongly recommend that a mechanism be developed to display the corrections used in the bulletin products. The Experts Group points out that an

IASPEI commission on seismological practise is considering extensions to IMS 1.0 to distribute such information. IDC and PIDC should be encouraged to participate in this process.

The Expert Group also points out the need for a formal procedure for validation. In addition, there should be standards for implementation and periodic checking of performance. The Group recommends that global models (large-scale regional models) continue to be tested, and points out the need for a high resolution crustal model. It is also noted that there are currently no teleseismic SSSCs available, nor are such corrections being developed within any CTBT related research so far.

Topic 2: Collection of Regional Calibration Information

Region 1

Region 1 (Northern Eurasia and East Asia): Collection of ground truth calibration data for many IMS stations in this area is progressing well. It is anticipated that high quality samples of such data for Soviet PNE events will become available at the Center for Monitoring Research (CMR) over the next 6 to 12 months from current contracts. Additional efforts are needed to collect comparable ground truth data and velocity models for other areas of this region, such as China, India, Pakistan, and Korea. Efforts by the individual NDCs/research groups to identify additional calibration and reference events from their regions should be encouraged.

The CMR Reference Event Database may be discontinued mainly due to restrictions in publishing the REB information and the delay in obtaining auxiliary data. The experts strongly support the ongoing efforts to make the IDC data available to the research community. The CMR Ground Truth Database is valuable and continued effort in maintaining this database is important. Deliveries of its updates to the IDC are expected with Release 4.

Region 2

Region 2 (Southwestern Asia and the African/Mediterranean area): The collection of many reference events of GT5 or better available in the Former Soviet Union and Europe was reported. These events are critical for model validation. The experts discussed several possible sources of additional information and recommended that research groups in the region should be queried to obtain calibration data including past refraction profiles and digital data that is not included in bulletins.

Local and national network locations are critical to developing reference events for calibration validation. WGB and the IDC should as appropriate use official diplomatic channels to encourage states signatories to support local operators to distribute calibration data. This reiterates and reinforces an important recommendation of last year's meeting.

Region 3

Region 3 (North America, Australia): As reported last year, considerable calibration information is available, but geographical coverage is poor. Aside from where United States SSSCs have been developed, no one has seriously looked for calibration data. Additional events, preferably of GT5 or better and magnitude >3.5 , should be identified. The experts recommend looking at regional PASCAL data as a source. In particular, events with good S waves and recordings beyond 5 degrees are needed. The current Ground Truth Database for this and other regions should be reviewed and revised where necessary.

The experts note that the U.S. Department of Energy has recently published detailed hypocenter information on United States nuclear explosions: http://www.nv.doe.gov/news&pubs/publications/historyreports/pdfs/DOENV209_REV15.pdf (185 pages).

General comments:

Every effort should be made to support “target of opportunity” experiments, particularly in areas such as South America which currently lacks detailed regional travel time curves. Special consideration should be given to large well-designed mine blast experiments, such as contained single blasts, that would provide unique source phenomenology information.

The number of events available for the Reference Event Database since 1994 is small, and it should be possible to analyze most of them comprehensively, given participation by the States concerned. Efforts should be made to expand the Ground Truth Database and, if possible, continue analyzing and expanding the Reference Event Database. As earlier recommended, this information, including associated waveform data, should be made available from the IDC and the prototype IDC in an unrestricted manner, through Web pages, AutoDRM, ftp, and direct electronic access to the relational databases.

Possibilities for improving the Ground Truth database include good (internal to the network) local network solutions, calibration shots, mining and construction explosions. The most useful data would be Ground Truth information for events in the REB. It may be desirable to consider some form of funding for collecting Ground Truth information on seismic events and delivering it to the IDC.

A need exists to evaluate and validate criteria for GT5 and GT10 reference events. The PIDC and others should continue to collect such events and report them to the IDC on a regular basis.

Topic 3: Application of Regional Calibration Information

The experts re-emphasized the recommendations from the previous meeting regarding the use of historic data and the further research required in developing analysis methods. In addition, some new points were made or expanded upon.

The experts consider the current plans for completion of the IMS network to be encouraging and expect that the implementation will lead to much improved location capability for events in all regions. There is some concern that the technical development of regional calibration models is being limited to some extent by the IDC software constraints. It is recommended that implementation of depth dependent SSSCs should remain as a long term goal of the IDC, independent of the current unavailability of the software needed to support their use in event location at the IDC. Development and implementation of improved databases of station parameters and locations, as well as their associated uncertainties wherever possible, are to be encouraged for use in IMS calibration studies. Additional research is needed to define optimal procedures for combining calibrated and uncalibrated data in the event location process.

The calibration program needs to help quantify both measurement and modelling errors. Our current understanding of the handling and impact of the total errors on location requires more research. Alternative location algorithms and procedures should be addressed. These algorithms include alternative norms (such as L1, uniform reduction), alternative optimization schemes (e.g. adaptive grid search, nearest neighbor algorithms), and alternative uncertainty assessment schemes (grid search, Monte Carlo methods, improved error ellipses). The calcula-

tion accuracy of travel-times using models should be high enough so that these errors are small compared to expected time pick errors.

Previously recommended work on cepstral depth estimation techniques should be continued. Positive progress was reported at the workshop that justifies the next stage of testing and validation in an operational context. Evaluation and testing of these available methods at the IDC is encouraged. Research into other methods for depth estimation need to be encouraged.

Techniques such as cepstral analysis, moment tensor, waveform modeling, and Joint Hypocentral Determination should be available, but not as isolated procedures. The experts recommend the development of a software package to present to the analyst, perhaps with depth confidence estimates.

The Experts Group note the availability of the LocSAT program on the prototype IDC ftp site. This program has the full location capability of the IDC location programs, including SSSCs, but does not require the ORACLE database; instead it uses standard files for input and output. The experts reiterated their recommendation that this program be enhanced by the PIDC developers with the capability to accommodate depth-dependent SSSCs as soon as possible.

The effects of SNR on location accuracy are known in general, but not in specific detail. It is recommended to design an experiment to evaluate the effects of onset picks by different analysts, by use of multiple frequency filters or other analyst aids, perhaps supplemented by master events. It should be recognized that timing problems associated with low SNR are 'asymmetric' in nature.

Topic 4: Validation of Regional Calibration Information

The experts reiterate their recommendations for establishment of a Location Calibration Board and formation and maintenance of a central database of calibration information. The IDC should use contracted services if the available resources at the IDC are not sufficient.

Multiple estimates of station corrections for individual IMS stations are expected from different research groups, and they may be submitted for consideration for implementation at the IDC. An effort should be initiated in the coming year to begin the development of the types of uniform procedures which will be needed to quantitatively compare and validate these competing SSSC estimates. Results of these validation studies should be made available to the calibration research community. Additional work directed toward the development of more reliable validation methods and acceptance criteria for ground truth events should be encouraged, especially to validate candidate GT5 events.

An appropriate mechanism for publication of calibration data needs to be developed to encourage and give credit to providers, and to provide an opportunity for review of the data. The experts reiterate their recommendation that Web and Ftp sites should be established at the IDC and the prototype IDC to receive contributed models, ground truth, and metadata (velocity models, travel time curves, phase/group velocity curves, crustal thickness, origins, arrivals, and waveforms). This would serve to encourage contributions and broaden access.

A project to establish rigorous procedures for validation of ground truth events should be initiated. This project should address all aspects of the validation problem, including the collection and storage of 'metadata' for future reference and comparison. It should also include procedures and validation metrics (see CTBT/WGB/TL-2/49) for documenting and

demonstrating improvement to the Location Calibration Board or Configuration Control Board. The project should also define procedures for periodic updates (checks) when new Ground Truth data become available. The participants were encouraged to use procedures for ground truth event validation as well as the metrics to assess the improvement when using newly derived SSSCs as listed in the 2000 CTBTO Calibration Programme Terms of Reference.

Topic 5: Future work of the Experts Group

In its future meetings, the experts should focus on examining the status of recommendations made at earlier meetings. The experts should acknowledge those recommendations that the IDC has begun to implement. Remaining recommendations should be re-examined, reiterated, and/or prioritized.

There is some concern among the experts that the recommendations presented to the IDC and Working Group B are too technical in nature. An executive summary could highlight the high priority recommendations, which should be kept to a few well focussed items separate from those addressed to researchers.

One idea forwarded to the experts group was that a subset of the participants at the next meeting could consider serving as the Location Calibration Board for a proposed set of candidate reference events or set of corrections. Results of the discussion and review might then be published in the Experts Group's report.

The next meeting could focus and/or organize the work around specific topics such as

- discussion of Ground Truth event selection and validation criteria,
- procedures for validating SSSCs,
- better understanding of fundamental location errors,
- location algorithms,
- depth estimation,
- a summary and inventory of available information as a function of region/country.

The next meeting needs to solicit participation from under-represented areas. The experts need to identify to the meeting organizer those individuals and organizations that need to be invited to participate, and how their participation could be financed.

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

F. Ringdal