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6.1 Seismic Event Location Calibration

Report from the IDC Technical Experts Meeting in Oslo, Norway 20-24 March 2000

6.1.1 Introduction

During the 1998 meetings of Working Group B of the CTBTO Preparatory Commission, the International Data Centre (IDC) Expert Group identified the need for highly-focused work to provide regionalized travel times to improve seismic location methods used in the IDC. The Expert Group suggested that initial focus should be given to the following geographical regions: North America, Eurasia, Northern Africa and Australia.

To assist with the developments of the IDC applications software relating to the location calibration problem, an informal meeting of the IDC Technical Experts Group on Seismic Event Location was held in Oslo, Norway on 20-24 March 2000. Sixty technical experts, coming from fifteen 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.

The IDC Technical Experts Group on Seismic Event Location has carried out considerable work in supporting the overall calibration effort, including the compilation of data of the types listed above. At its first meeting in January 1999, the Experts Group 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).

The second meeting of the Experts Group (20-24 March 2000) 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 Release 3 of the IDC software
- To develop a plan for future extensions and improvements of this regional correction data base, to be incorporated into future IDC software releases
- To review progress in the general recommendations from the January 1999 meeting, 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 Release 3 of the IDC applications software and for implementation in the longer term.

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 for calibration in Release 3.

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 information for seismic events was presented, and will be communicated to the IDC and the prototype IDC. 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 for IDC Release 3
Topic 2: Collection of Regional Calibration Information
Topic 3: Application of Regional Calibration Information
Topic 4: Validation of Regional Calibration Information

The results of the Working Groups were presented and discussed in a plenary session. These discussions have provided the basis for the recommendations presented below.

6.1.4 Recommendations

General

The Experts Group considers it essential for the success of the calibration program that States Signatories contribute actively toward this purpose, 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 Group recommends that the IDC make openly available to the scientists involved in the 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 will be essential for future IDC development. The Experts Group recommends that the prototype IDC should 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 responsibility for these calibration data and the associated processing software will over the next several years be transferred from the prototype IDC to the IDC on a stage-by-stage basis.

The Experts Group commends the IDC for preparations taken to begin an external calibration program. The Group recommends that this program give high priority to facilitating collection and validation of ground truth and waveform data.

The Experts Group considers 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 Group recognizes the valuable experience obtained from the recent chemical calibration explosions in Kazakhstan and Israel. The Experts Group recommends that the PTS solicit from States Signatories waveform data recorded on national seismic stations of such calibration explosions.

Site survey data collected by the PTS should be made openly available to States Signatories. Consideration should be given by the PTS to using GPS to check the location of relevant surrogate stations, such as nearby station during certification of IMS installations. The IDC and prototype IDC should provide a mechanism for archival and distribution of historical non-IMS data to promote calibration. The PTS should place a priority on connecting auxiliary seismic stations to the GCI for purposes of collecting calibration data as soon as possible.

Topic 1: Implementing regional corrections for IDC Release 3

For Region 1 (Northern Eurasia and East Asia) there will not be additional source-specific station corrections (SSSCs) beyond the Fennoscandian SSSCs already implemented in Release 2.

There is a reasonable chance that SSSCs will be available, possibly for most of Eastern Asia, by Release 4. Complete validation of corrections by this time will be more problematic.

For Region 2 (Southwestern Asia and the African/Mediterranean area) no travel time calibrations will be available for the Release 3 delivery in 2000. Delivery of a preliminary set of limited regional travel time corrections (surface source only with conservative modeling errors) may be available late in 2001 suitable for incorporation into Release 4 delivery, Refined and extended calibrations will be available in 2003.

For Region 3 (North and South America, Australia) there have been some recent developments. SSSCs for all IMS stations in Canada and the USA were implemented at the prototype IDC in February 2000, and will thus be available for IDC Release 3 delivery. The work on SSSCs derived from a 3-D model for this region is now considered to be sufficiently advanced that it should be possible to document the methods and data used to generate the corrections, and validate them, by November 2000.

Topic 2: Collection of Regional Calibration Information

Regional review

Region 1 (Northern Eurasia and East Asia): A large amount of Ground Truth data exists for this region, e.g., Soviet PNEs, but most of the IMS stations were not installed at that time. This means that the use of surrogate stations will be required. Many regional travel-time curves, models, and geological/geophysical surveys also exist, but are not always easily available. It would be desirable to make an effort to obtain this type of data. The recent calibration explosions in Kazakhstan are excellent examples of the type of calibration events that will be the most useful for future developments.

Region 2 (Southwestern Asia and the African/Mediterranean area): Most of the information available for this region is from geological/geophysical surveys and regional travel-time models. Local travel time tables (and curves) as well as crustal and upper mantle velocity models are readily available for Egypt, Turkey, Israel, Romania, East Africa, and several other countries in the region. As with Region 1, much additional information exists, but is difficult to access. The amount of Ground Truth information is limited, but a notable recent development is the Dead Sea calibration explosion of November 1999.

Region 3 (North and South America, Australia): Considerable calibration information is available, but geographical coverage is poor, particularly for the eastern U.S., Canada, Alaska, Mexico, Central and South America. Additional events, preferably of GT5 or better and magnitude >3.5, should be identified. The current Ground Truth Database for this and other regions should be reviewed and revised where necessary.

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.

Existing facilities (stations and arrays) with enhanced capabilities (such as long-period arrays) should be maintained as part of the IMS seismic system.

The term "Calibration Event Bulletin" is misleading, and should be changed to Reference Event Database (REDB). 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 both the Reference Event Database and the Ground Truth Database. 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 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.

Topic 3: Application of Regional Calibration Information

Use of historic data

Historic data may be used to derive models, including travel time curves. It may be possible to perform Joint Hypocentral Determination analysis on old data and stations and apply derived corrections to new IMS stations. Care is needed in questions of timing, station location, and instrument changes for old stations; the network operators should be contacted if possible. Instrument response changes can affect phase arrival time picks; if repeated events are available they can be used to check consistency. Careful checking for outlier data should be made.

The historic database should be exploited to identify and validate GT5 events and GT5 clusters. In cases where IMS stations are not available, the event-specific corrections to surrogate IMS stations and to stations with unique locations and validated operational characteristics should be used.

Processing techniques

The Experts Group draws attention to 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 prototype IDC and the IDC should be prepared at any time to examine new techniques in location estimation.Examples for relatively short term consideration include full use of the Joint Hypocentral Determination method with events in the reference data base, cluster analysis, and local-only locations. In the longer term, grid search techniques and correlation methods for location, 3-D ray tracing by Gaussian beams or finite difference, and 3-D tomography should be considered. Depth estimation is a continuing concern, elevation corrections may be helpful, and depth phases for refracted arrivals might be useful.

The Experts Group recommends that error estimation of phase arrival time picks should be re-examined. The general feeling of the experts is that errors are currently underestimated. It was suggested that a single Gaussian pdf should not be used, but some pdf with "tails" to handle large errors. Better analyst tools could include use of array analysis to find coherent information, and multistation methods such as generalized beamforming to check arrivals.

Suggestions were made that analysts could be presented the ranges of predicted arrival times based on modeling error and/or analysts could specify a range of arrival times for low SNR picks. It is desirable that filter parameters used in interactive processing should be recorded.

Cepstral techniques for the identification of depth phases should be further investigated. The long term goal for depth dependent regional corrections is reiterated. Depth-dependent SSSCs should be accommodated in the IDC software. Wavelet decomposition and other automated methods for the more consistent identification of phase onsets, particularly Lg, should be further developed and tested.

Baseline errors are expected to result when combining calibrated and non-calibrated station sets. These baseline incompatibilities are expected to result in origin time and/or depth shifts until all phases and stations are calibrated. However, uncalibrated data should not be excluded. At this time inverse variance weighting is a reasonable approach to combining calibrated and uncalibrated data. Nevertheless, calibrated and uncalibrated data should be combined only when the variances used for each accurately reflect the relative uncertainties. It was also suggested to calibrate whole regions so that we do not mix uncalibrated and calibrated stations; as an example, it may be feasible to add to the calibrated Fennoscandian region incrementally.

Topic 4: Validation of Regional Calibration Information

Assessment of current efforts

The Fennoscandian SSSCs have been implemented, and improvements in location has been documented for Fennoscandian and Kola events. It appears that a single regional model may be useful for all of NW Russia. However, this is not fully validated. On validation, a period of testing is needed before a CCB proposal.

The SSSCs for North America that were approved for implementation at the prototype IDC in February 2000 are based upon a division of Canada and the USA into three distinct regions, the assignment of a travel-time curve to each region, and a simple linear combination of travel times in each region. The data and the methods used are quite well-documented. The location improvements demonstrated in the validation of these SSSCs were very modest, and illustrate the need for more sophisticated corrections based on additional data and more complex models. Some of the data used for validation was of questionable quality.

The basic divisions for North America are reflected in the corrections described above. The main boundaries are quite well-defined but there is scope for refinement of the travel-time curves and subdivision into additional regions. Well-calibrated events should be directly used in the derivation of the correction surfaces. For North America, enough information should be available to do this for station PDAR as a test case.

Validation data bases

Validation databases should be chosen carefully, and the phase arrivals should be repicked. Repeated events should be exploited to check data quality. The importance of the seismic data (i.e., picks) equals the importance of the GT data. It is important that the phase data used for validation be obtained through careful analysis of waveform data, ideally from IMS stations.

Historic data using past nuclear and chemical explosions has been used extensively in the work for the refinement of 3-D models and the travel curves used for each region, respectively. The accuracy of such information, particularly for chemical explosions, should be carefully assessed and adequate documentation and references must be provided. Newly available commercial satellite imagery will be useful in this regard.

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.

Configuration Control Board and Location Calibration Board

The Experts Group reiterates the recommendation for establishment of a Location Calibration Board (LCB). Currently, the Configuration Control Board (CCB) addresses the effects on the overall system (e.g. integration) of new corrections, to a greater extent than their scientific validity. For proposals involving location calibration corrections, additional expertise should be drawn upon. The LCB would comprise a designated panel of experts to review CCB proposals relating to location calibration and make recommendations to the CCB of the IDC concerning their acceptability.

A period of testing will be required before a CCB proposal relating to location calibration can be considered. The R&D testbed at the prototype IDC will be helpful for this purpose. It would be desirable for the CCB proposal requirements to be documented, with examples, and made easier if possible. CCB proposals should continue to be placed on the prototype IDC Web Page. The main responsibility for validating calibration information should remain on the proposer.

Validation metrics

Methods of calculating error ellipses from data rather than *a priori* should be explored, and the two methods compared. Possibilities are repeated events, bootstrapping, and Joint Hypocenter Determination using groups of events.

An important question is how to validate partial SSSCs. One desirable task is to determine the crossover between Pn, Sn, and P, S, which is region-dependent. There is a question as to whether we should be correcting IASPEI or finding new absolute tables at regional/local distances; the IASPEI phases are not in general the ones present. It was pointed out that none of the national networks uses IASPEI to locate events. It would be desirable to have the national travel-time curves for all regions. States Signatories are again requested to provide all available regional travel-time curves. However, there is a problem in matching such local/regional

tables with IASPEI for teleseismic distances, and with other regions, as seen in a study in Fennoscandia.

The validation metrics should be revised to include a measure of how well the proposed correction surfaces fit observations at the station for events of known location. The unit test metrics given in WGB/TL2-18 still appear to be appropriate, but may need to be revised. Concern was expressed that situations may arise where the introduction of new corrections may cause a small numbers of events to be significantly worse located than before. The evaluation metrics listed in WGB/TL2-18 should be augmented with tools that enable such situations to be detected.

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