



NORSAR Scientific Report No. 2-2002

Semiannual Technical Summary

1 January - 30 June 2002

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Kjeller, August 2002

6 Summary of Technical Reports / Papers Published

6.1 Seismic Event Location Calibration

Report from the IDC Technical Experts Meeting in Oslo, Norway 22-26 April 2002

6.1.1 Introduction

The International Data Centre (IDC) Technical Experts Group on Seismic Event Location held its fourth annual meeting in Oslo, Norway on 22-26 April 2002. The meeting was held jointly with the IDC Technical Experts Group on Seismoacoustic Event Screening. The purpose of the meeting was to support the ongoing calibration and screening 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-six technical experts, coming from twelve 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 and third meetings of the Experts Group in March 2000 and April 2001, and the results were subsequently presented to Working Group B (CTBT/WGB/TL-2/49 and CTBT/WGB/TL-2/61). The fourth meeting of the Experts Group (22-26 April 2002) had the following objectives:

- To review new developments of common interest to location calibration and event screening, with special emphasis on event depth determination and computation of location confidence ellipses
- To report on and review progress of ongoing research work on location calibration, including calibration consortia and PTS Phase 1 calibration contracts

- To review proposals for detailed station-specific regional location corrections, with particular emphasis on 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 operational 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 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 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 general geographic regions being considered initially. Information was provided about the current CTBTO Calibration Programme. Progress was reported at the workshop by U.S sponsored consortia, by CTBTO sponsored contractors and by several other research groups.

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 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. 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 sparse seismic networks as well as improved azimuth determination for regional arrays were presented and discussed. The application of special location and depth estimation 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 America, Australia, Global models

The 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 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. 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

Main results

Since the 2001 workshop, participants reported considerable progress in reference event data collection, GT criteria, and regional calibration. Reference event lists have significantly increased over the last year. New GT category criteria have been proposed. Regional calibration has demonstrated reduced bias (absolute errors) and decreased uncertainty (smaller error ellipses) in accordance with the goals of the IMS calibration effort.

Regional corrections have been implemented at the IDC for IMS stations in northwestern Eurasia and northern America. Work is continuing on developing such corrections for the remaining priority regions, and encouraging results have been achieved.

For example, for much of Eastern Asia, preliminary work on source-specific station corrections (SSSCs) for Pn arrivals has given very promising results suggesting that it will be possible to achieve or exceed the uncertainty goal of 1000 km². For example, it was reported that relocation studies using Soviet explosions recorded by about 90 regional stations have succeeded in reducing the median 90% error ellipse to 200 km² for these explosions, using model-based analysis combined with an interpolation approach to provide preliminary SSSCs. More limited validation studies conducted using a sparse IMS/surrogate network have documented improvements in location accuracy to significantly better than 10 km. Some cautions need to be exercised in extrapolating these results to smaller events, but all indications are that significant improvements in location will be obtained by applying SSSC corrections to the IMS stations in this area.

Validation data sets

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 development of a validation data set be undertaken. This validation set should include GT events of various categories, and should contain all relevant information (metadata) about the events in the data base. Before delivering such datasets to the IDC archive, 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. WGB should consider arrangements to make these data available from the IDC without restrictions to the research community.

The Expert Group re-emphasizes 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, and the experts recommend that such corrections be developed.

Validation metrics

The initial set of validation metrics suggested by the 1999 Workshop (CTBT/WGB/TL-2/18) should be updated. The experts recommend that the metrics below to be used as a common ground to evaluate the performance of SSSCs:

- Average and median improvement in epicentre mislocation for all relocated events with depth fixed to the GT depth.
- Average and median reduction in the size of 90% error ellipses where these error ellipses are adjusted to GT accuracy
- Actual coverage of the 90% confidence region (adjusted to GT accuracy).
- For events where accurate origin time is available:
 - average and median improvement in origin time;
 - origin time error should provide 90% coverage
- Percentage of events improved/deteriorated with respect to GT epicentres
- Percentage of events improved/deteriorated by more than 20% w.r.t. GT epicentres; average/median improvement and deterioration in km

The experts expect that additional metrics will be developed over the next few years which may provide more robust comparisons/evaluation capability. In order to compare corrections that have overlapping geographical coverage, a central archive should be established at the IDC to encourage the international community to contribute their insights and evaluation.

It would be desirable to develop a simpler “measure of performance” that would indicate which set of models/calibrations are statistically “better”. It was recognized that the problem has multiple dimensions and location performance is more complicated than what can be described by a single number, but it will be easier to communicate to non-experts if the advantages/disadvantages of multiple overlapping SSSCs can be ranked in some sense.

Implementing preliminary corrections

The experts recommend that the preliminary sets of SSSCs that are now available should be considered for testing at the IDC as soon as possible along with existing available sets of offline validation test sets. Furthermore, such testing should include computations of multiple locations of REB events for open evaluation by the expert community. Multiple models should be tested. Input and results should be available in an open and transparent database with results compared to current practice. All experts are encouraged to provide their GT events, velocity models and SSSC corrections, including supporting information (meta-data), to the IDC as soon as possible.

Transparency

The experts again 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. The experts re-emphasize concerns over lack of transparency in IDC bulletin products that reflect corrections applied to travel times, azimuths, and slownesses for location. A mechanism for access to and distribution of corrections stored in databases and flat-files should be developed.

Need for wider participation

The experts are concerned 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 reference 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 reference event collection.

Future work

The IDC contractors, U.S.-sponsored consortia and other research groups are expected to deliver to the IDC a variety of proposed SSSCs in the coming year. Evaluation and validation of these corrections will require substantial additional research study. The experts consider that merging SSSCs from different study groups with different methodologies in an operational system presents a significant challenge. It is recommended that the IDC begin planning for such a continuing research program.

Encouraging results were presented for depth phase detection and identification. 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.

The experts consider that investigation is needed into the possibility that analyst time picks (as well as automatic onset estimates) are late for low signal-to-noise ratio recordings. Such biases would result in different apparent baselines for regional and teleseismic phases. More generally, presentation and discussion of IDC analyst procedures and of the problems facing the analysts should be considered for the future.

Collection of a set of reference events will continue to be a priority with emphasis on precise hypocenters and origin times and a good geographic coverage. The reference events should be chosen so as to keep usage of surrogate (non-IMS) stations to a minimum. For clusters of events it is recommended that a few, well-constrained events be chosen (using the smallest confidence ellipse as a selection criterion). Reference events should be recorded regionally and should comprise a range of magnitudes.

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

F. Ringdal