SOURCE SPECIFIC STATION CORRECTIONS (SSSCS) FOR INTERNATIONAL MONITORING SYSTEM (IMS) SEISMIC STATIONS IN NORTH AFRICA, MIDDLE EAST AND WESTERN ASIA

Group - 2 Consortium

SAIC, University of Colorado, Harvard University, University of California San Diego, Multimax, and Geophysical Institute of Israel

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ABSTRACT

To date, IDC regional travel time corrections have been successfully implemented for Fennoscandia and North America. Corrections and associated modeling errors to Pn, Pg, Sn, and Lg IASPEI91 travel time tables are specified on 1 by 1 degree latitude and longitude "source specific" grids within 20 degrees of each International Monitoring System (IMS) station. International Data Center (IDC) location software is configured to read and apply these grids when locating events in the Reviewed Event Bulletin (REB). In order to develop regional travel time corrections for IMS stations in North Africa, Middle East, and Western Asia, a consortium was formed of experts in IDC software integration/testing/validation, regional/global body/surface-wave tomography, tectonic regionalization, 3D ray-tracing, and ground truth (GT) data collection with the goal to improve location accuracy and precision while maintaining honest 90% coverage ellipses.

The three-year R&D program will provide Source Specific Station Corrections (SSSCs) for all IMS primary and auxiliary seismic stations in the region. Corrections will be developed, tested, and validated in two phases. A preliminary set of SSSCs will be delivered and tested by late 2001. A refined set of SSSCs will be delivered and tested by early 2003. The preliminary set will develop corrections for surface sources only based on an initial preliminary regionalization and set of crustal and upper mantle models. The 3D model will be based on a hierarchy of global 3D models, regional models, and tectonic regionalization. Travel times will be computed by 3D ray tracing from each station to a grid of source locations. Modeling errors for the initial correction set may be conservatively large. Meanwhile, a concerted effort has begun to gather ground truth (GT) location data in the region for validation. All GT origins, GT arrivals, velocity models, regionalizations, SSSCs, and metadata will be delivered for testing and validation. The preliminary set of SSSCs will focus the research team on problem areas and issues. GT data collection and analysis will continue throughout the entire program. Problem areas and technical issues will be addressed to refine models and GT data collection for a second and final delivery.

OBJECTIVE

The objective of this research is to develop, test, validate and deliver source specific station corrections (SSSC) for regional phases (Pn, Sn, Pg, Lg) up to 20-degree epicentral distances for International Monitoring System (IMS) stations in North Africa, the Mediterranean, Middle East and West Asia. It is expected that regional SSSCs will improve locations by both decreasing individual absolute errors (bias) and improving precision (reduce error ellipses) w.r.t. current IDC practice.

RESEARCH ACCOMPLISHED

Introduction

Improvements both in seismic location and accuracy are crucial for monitoring the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The development and application of regional SSSCs for IMS stations in Fennoscandia and North America (Yang et al., 2000d, Yang et al., 2000e) have demonstrated that path dependent corrections relative to the default IASPEI91 travel times are capable of improving event locations and reducing uncertainties. To further develop and validate regional SSSCs for IMS stations in North Africa, the Mediterranean, Middle East and West Asia, a consortium, called "Group 2" has been formed. The Group 2 consortium consists of scientists from SAIC, Harvard University, University of Colorado Boulder, University of California San Diego, Multimax and the Geophysical Institute of Israel with broad expertise in collection and maintenance of ground truth data, tectonic regionalization, construction of global and regional 3D models, computation of travel-times in 3D media, joint hypocenter determination (JHD) as well as testing, validation and integration of mission critical software.

The IDC software uses the IASPEI91 tables in its location module to obtain predicted travel times for a suite of seismic phases in various distance and depth ranges. However, the IASPEI91 travel times, being 1D global averages, can considerably deviate from true travel times at regional distances. The difference can be as much as 5-10 seconds. This not only affects event locations but often results in very large coverage ellipses because the estimated travel time uncertainties (modeling errors) incorporate the large discrepancy between predicted and true travel times. The application of SSSCs is expected to improve locations and reduce the size of error ellipses while still maintaining 90% coverage level, owing to the better travel time and modeling error estimates. SSSCs are path dependent travel time corrections relative to the default IASPEI91 tables for a given phase at a station. They are specified on a rectangular latitude/longitude grid, where both a correction and a modeling error are assigned to each grid point.

The Group 2 consortium will follow model-based approaches to constructing SSSCs. Ground truth data will be used for validation purposes only. Figure 1 shows the IMS stations (black triangles), together with a circle of 20-degree radius around the stations, for which the Group 2 is responsible. The envelope of these circles depicts the consortium's primary region of interest.

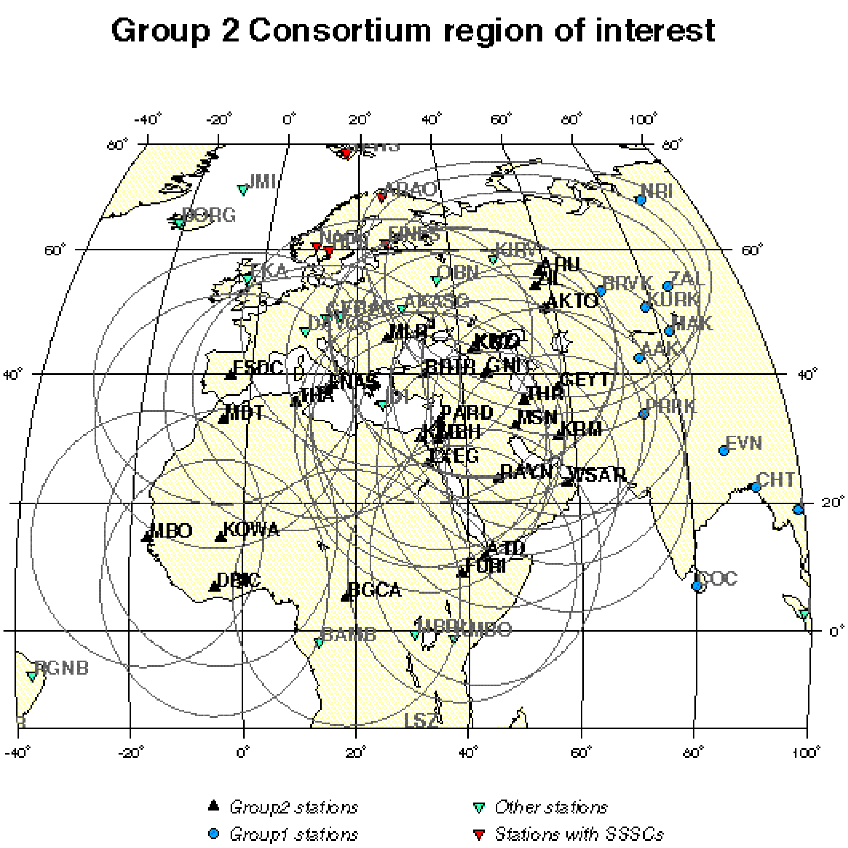

Figure 1. Group 2 region of interest. Group 2 IMS stations (black triangles) are drawn with their surrounding 20-degree circle. Note the overlap with Group 1 stations (blue circles). Other IMS stations are plotted as inverted triangles.

Travel time corrections will be developed, tested and validated in two phases over three years. In the first phase preliminary corrections will be developed based on readily available models for the region of interest. The second phase will provide a refined set of corrections utilizing improved models, error estimates and algorithms. Construction of improved 3D hybrid models (a combination of global and regional velocity models) from which travel times are derived via 3D ray tracing will be the primary focus of the consortium.

The validation of the corrections will be based on reference events with location accuracy of 5 km or better. Collection and validation of such reference events will be an ongoing major effort throughout the entire project. Validation of the SSSCs requires that the locations meet specified metrics in order to demonstrate improvements when the corrections are applied.

Ground truth data collection

In order to test and validate the model based corrections it is essential to obtain a set of reliable reference events spread over the region of interest. Since the expected improvement in location is on the order of 10 km, the location of reference events should be known within 5 km accuracy or better. Besides events with exactly known hypocenters, such as nuclear explosions and calibration shots, events can also be selected from seismic bulletins, provided that their location meets the following criteria:

- 10 or more stations at $\Delta < 250$ km
- 10 or more time-defining phases
- minimum distance of recording stations <= 30 km
- largest azimuthal gap < 120 degrees

and desirably:

- magnitude > 3.5
- depth < 35 km
- phases recorded at IMS stations or surrogates
- first arrivals recorded beyond 250 km

Although the above criteria are similar to those developed for GT10 or better events (Dewey and Kork, 2000), they appear to be stringent enough that events meeting the above requirements will be located better than 5 km. The selected events will be subject to further expert review within the consortium.

Reference events are selected from the CMR Nuclear Explosion and Ground Truth databases (Bondár et al., 2000, Yang et al., 2000a, Yang et al., 2000b), the CMR Calibration event bulletin (Yang et al., 2000c), the PIDC/IDC REB, the NEIC and ISC bulletins (Engdahl et al., 1998) as well as national and local network bulletins in the region. Chemical explosions identified with a mine or a quarry can also be accepted if the size of the quarry does not exceed 5 km. Figure 2 shows the set of reference events we have collected so far. This effort will continue throughout the 3-year program.

When testing and validating the models, it is irrelevant which stations recorded the event, therefore phase arrivals are collected from all the recording stations through established contacts with local network operators. We follow the principle that reference events used for the validation of the models will not be used in the validation of SSSCs.

As part of a cross-validation procedure empirically derived path-dependent corrections obtained from Joint Hypocenter Determination (Douglas, 1967, Dewey, 1991) will be compared to model based SSSCs. To perform this task, event clusters, recorded by IMS stations, their surrogates as well as other well established teleseismic stations are collected. Station corrections and statistical scatter of clusters will be used as one source of information in estimating model errors.

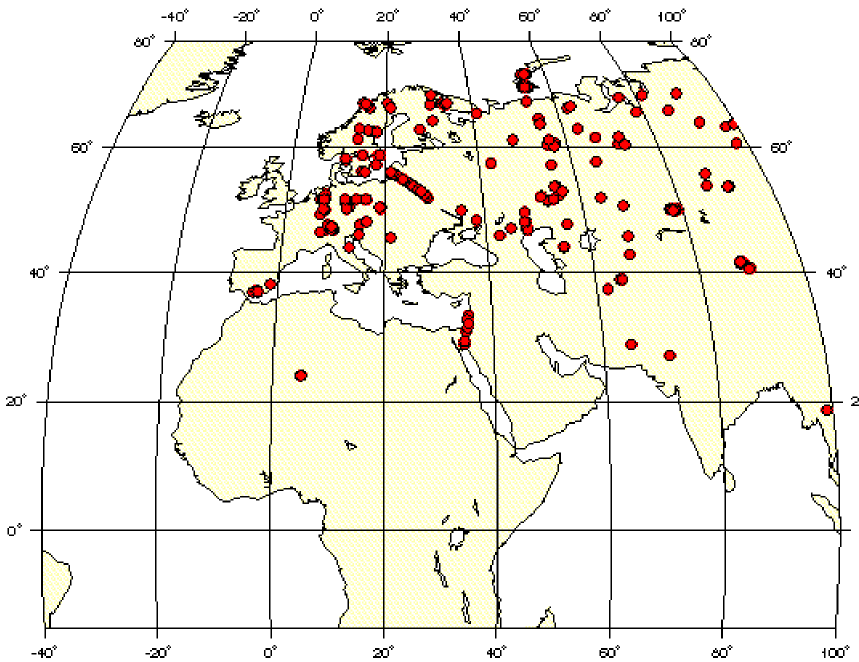

Figure 2. Reference events located with 5 km accuracy or better in the region of interest.

Model construction

Currently available global 3D models, although they adequately describe the gross features of the Earth, have not yet the resolution (especially in the crust and uppermost mantle) required for regional calibration. Therefore one of our main objectives is to construct a 3D hybrid velocity model that has sufficient resolution to generate path dependent travel times on a 1 by 1 degree grid. To accomplish this goal we will combine global mantle P and S models (Boschi and Dziewonski, 1999, Bijwaard et al., 1998) with global and regionalized uppermost mantle (Gudmundsson and Sambridge, 1998), crust and sedimentary models (Mooney et al., 1998, Laske and Masters, 1997, Seeber et al., 1997) as well as local and regional crust models. New 1 by 1 degree sedimentary models under development will also be utilized.

Figs. 3 and 4 provide a comparison between P and S global models in the Middle East region. The P wave velocity model was obtained from P-wave tomography (Bijwaard et al., 1998), while the S model is derived from surface wave tomography (Villasenor et al., 2000). Fig. 5 shows preliminary correction surfaces calculated from the S model. A hybrid model can optimally exploit the advantages of different methods.

In some regions the best achievable calibration information is limited to regionalized travel time curves or local velocity models. However, even in those regions we will apply rigorous 3D ray tracing. The hybrid 3D model will be constantly refined as it is tested against ground truth data and empirical regionalized travel time curves until an acceptable fit is achieved.

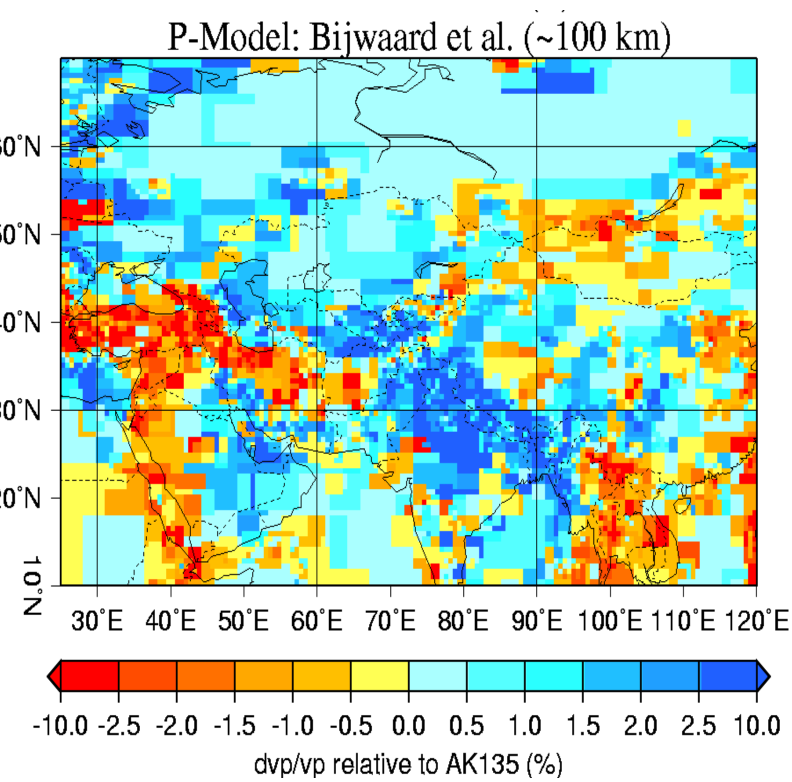

Figure 3. P wave velocity model (Bijwaard et al., 1998) at 100 km depth in the Middle East region relative to AK135.

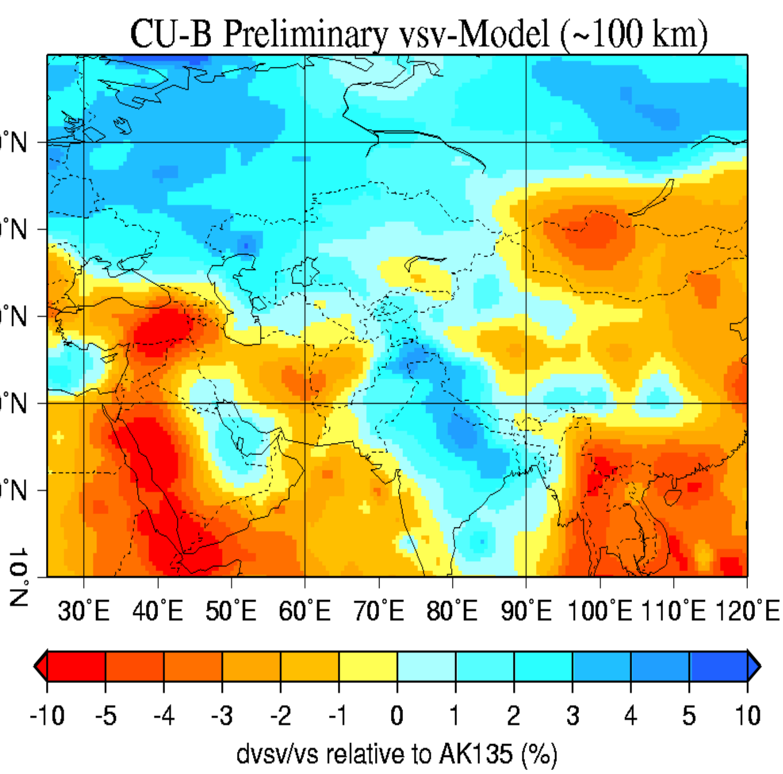

Figure 4. S wave velocity model at 100 km depth in the Middle East region relative to AK135 (Villasenor et al., 2000).

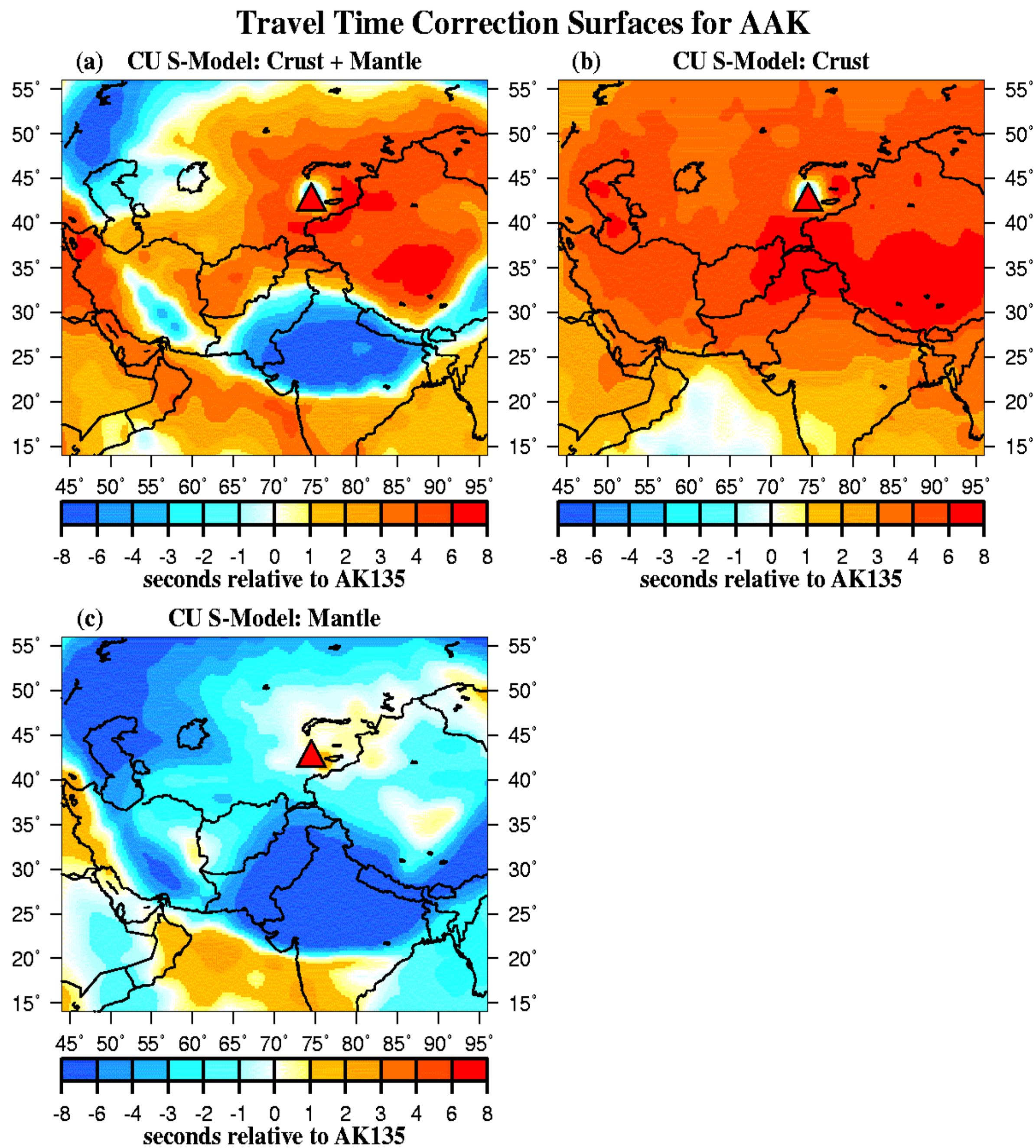

Figure 5. Preliminary correction surfaces calculated by 3D ray tracing through the S wave velocity (Villasenor et al., 2000).

One important aspect of the model construction is the estimation of modeling errors at each grid point, i.e. the uncertainty in the predicted travel times. The modeling errors will be estimated from the scatter of travel times caused by small perturbations in the model parameters, as well as from the comparison of travel times obtained by different ray tracing algorithms and empirical JHD station corrections. The modeling errors must be conservative enough to ensure actual 90% ellipse coverage.

CONCLUSIONS AND RECOMMENDATIONS

Testing and validation plan

Testing and validation requires a representative set of reference events. Previous studies (Bondár et al., 1998, Yang et al., 2000d) have shown that SSSC testing results are ambiguous when limited to GT10 events (events located with 10 km accuracy). Thus, only GT5 or better events will be used for validation testing. Reference events that were used in the model development will not be used in the validation procedures. Validation requires proof that location accuracies are improved as well as the 90% ellipse coverage is maintained.

Validation testing consists of two stages: off-line unit testing and integration testing. Off-line unit tests are designed to quantitatively measure the improvements in location, uncertainties and coverage when corrections are applied with respect to default travel time tables. Validation tests will be conducted in accordance with the recommendations of the CTBT Working Group B Location Calibration Expert Group (CTBT/WGB/TL-2/18, CTBT/WGB/TL-2/48) and the procedures established in past CMR calibration efforts (Bondár and North, 1999, Bondár et al, 1999, Yang et al., 2000e). We will provide the metrics recommended in CTBT/WGB/TL-2/18:

- the median mislocation of GT events should be significantly reduced
- mislocation should be reduced by 20% or more for the majority of the events
- median confidence ellipses should be reduced in area, and the coverage (percentage of GT events lying within the confidence ellipse) should be the same or better
- confidence ellipses should be reduced by 20% or more for the majority of the events
- fit, as expressed by residuals or their variance, should be similar or better

Besides those recommended by WGB we may construct additional metrics to measure the performance of the SSSCs (for instance, we will require that the ellipse coverage be consistent with the confidence level).

Integration tests will be carried out on the CMR R&D Test Bed in order to ensure that the new tables added to the system will not negatively influence the overall performance of the full IDC software suite.

Time schedule

The three-year project is divided into two major phases. Starting in March 2000, Phase 1 (0-18 months) will provide a set of preliminary SSSCs based on the initial models. In this phase SSSCs will be computed for sources at 10 km depth, in order to avoid projecting the effects of low velocity sedimentary layers into the deeper crust and upper mantle propagation. Slowness and azimuth corrections will not be addressed at this stage. Phase 1 schedule is outlined as follows:

- Phase 1- Preliminary Corrections (0-18 months)
  Select methodologies, models and data
  Develop 3D models, regional TT curves and event clusters
  Construct SSSCs
  Testing, validation and documentation
  Integration testing on CMR R&D test bed
  Deliver preliminary corrections

The IDC software will not be capable of utilizing full SSSC depth dependence until the end of the scheduled program. Therefore initial Phase 1 SSSCs will be provided for a source depth of 10 km consistent with those already developed for Fennoscandia and North America. Shallow crustal structure will be included at each station, however it is undesirable to map shallow crustal structure into corrections for the mid crust and upper mantle. In Phase 2 special attention will be given to areas of deep seismicity (h>50 km) such as Romania and parts of the Mediterranean.

Phase 2 (12-36 months), beginning in 2001, will provide the final, refined set of corrections. During this phase knowledge acquisition will be focused on gaps in models and GT events identified during Phase 1. Model based slowness and azimuth corrections will be compared to empirical slowness-azimuth station corrections (SASCs), and if they are proven superior to empirical corrections, they will be included in the Phase 2 products. The overlap between Phase 1 and Phase 2 allows us to address problems identified during Phase 1 at an early stage. The outline of Phase 2 schedule largely follows the Phase 1 plan:

- Phase 2- Refined Corrections (12-36 months)
  Select revised methodologies, models and data
  Develop 3D models, regional TT curves and event clusters
  Construct improved SSSCs including source depth
  Construct and examine model based source specific SASCs
  Testing, validation and documentation
  Integration testing on CMR R&D test bed
  Deliver refined corrections

Deliverables

The consortium will deliver the following products:

- SSSCs (Source Specific Station Corrections)
- Possibly SASCs (Slowness and Azimuth Station Corrections)

Validated travel time, slowness and azimuth corrections will be provided for each IMS stations within the region of interest over a horizontal grid of 1 degree or less for the regional phases Pn, Pg, Sn and Lg up to 20-degree epicentral distances. The corrections will be based on velocity models, possibly combined with empirical ground truth observations. The corrections in each grid point will be accompanied with estimated uncertainties.

- 3D Velocity models

The 3D models, from which the delivered SSSCs and SASCs are derived, will also be delivered.

- Reference events

Ground truth data collected for the testing, evaluation and validation of the models and corrections will be incorporated in CMR databases with event origins and station arrivals.

- Documentation

Technical reports will be prepared to provide appropriate documentation for each of the above products.

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