REGIONAL LOCATION CALIBRATION IN ASIA

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Sponsored by National Nuclear Security Administration
Office of Nonproliferation Research and Engineering
Office of Defense Nuclear Nonproliferation

Contract No. W-7405-ENG-36

ABSTRACT

Seismic event location for global nuclear explosion monitoring is a multi-faceted problem. This paper presents a spectrum of issues and efforts involved in improving location performance worldwide. Our efforts are largely designed around providing validated, rigorously calibrated travel times, azimuths, and slownesses along with accurate error estimates. To do so entails a significant effort that includes data mining, data integration, database management, developing optimal 1-, 2-, and 3-D Earth models, using the Earth models to predict wave propagation, developing corrections and errors for travel times, azimuths, and slownesses, and validation of all products. Results presented here will focus on Asia.

Previous work has shown that non-stationary modified Bayesian kriging of travel-time residuals successfully improves regional seismic event location, and this method is being extended to calculate corrections for azimuth and slowness. The ability to krige over 3-D Earth models is also being implemented. In order to produce the most useful corrections, we require accurate ground truth. For this we are continuing efforts to create a location database consisting of the best available seismic event locations and the most accurate and precise travel times. Building this database relies on participation from universities, other National Nuclear Security Administration (NNSA) laboratories, and contacts in private industry. Through the kriging procedure we are able to stabilize location algorithms, but the ultimate usefulness of the corrections themselves is directly related to the quality of the ground truth from which the corrections are derived. Indeed, epicentral mislocations from location algorithms (EvLoc) using travel-time correction surfaces are directly proportional to the location errors of the ground truth used to generate the corrections.

In aseismic regions, corrections for travel time, azimuth, and slowness are predicted from optimal Earth models using one of the following methods, depending on application: TauP, ray bending, reflectivity, or finite difference. We have developed a model-building tool that can incorporate many different types of data, from surfaces (Moho, bathymetry, topography), to local or regional 1-, 2-, and 3-D models, to reflection profiles, to point data. Numbers of layers are defined within prominent sections of the lithosphere, and interpolation between data points is used to create a smooth, self-consistent 3-D Earth model.

OBJECTIVE

The objective of this work is to improve seismic event location in Asia. We achieve our objective through a multi-faceted approach encompassing database development, data integration, geophysical model building, numerical simulation of wave propagation, travel-time kriging, location algorithm development, and validation.

RESEARCH ACCOMPLISHED

A new location database is being compiled to provide a preferred origin and a superset of arrivals compiled from all available global and regional catalogs. The effort has focused on merging global and regional seismic event bulletin information with Los Alamos National Laboratory (LANL)-generated phase arrival and waveform data using a combination of PERL scripts and the ORLoader codes. The result is a set of database tables that contain integrated seismic event data from many sources. These tables are the foundation for the creation of CSS3.0 ***assoc*** and ***arrival*** tables that will be used specifically for event relocations. Merging event bulletins and renaming of seismic phases follow separate pre-determined ranking schemes. As of this writing, we have about 600,000 preferred origins and 14,000,000 arrivals (excluding ISC and LANL picks). Of these arrivals, 8,500,000 are either P or Pn. About 150,000 waveforms have been tied to the database (748 from chemical explosions; 1086 from nuclear explosions) and 45,000 picks are being incorporated from LANL (see also Begnaud *et al*, this volume).

The InSAR component of our ground truth acquisition effort has produced some interesting global and regional results. Figure 1 shows theoretical predictions of ground displacement for several different fault orientations and depths. These results are used along with statistical seismicity patterns derived from the PDE catalog to predict the number of InSAR-observable earthquakes per year on a 2.5^{o} grid around the globe (Figure 2) (Earle and Cogbill, submitted manuscript). These results seem encouraging on the whole, but in a follow-on study in China, a number of problems were encountered that illustrate the difficulties in applying InSAR to smaller events (see Peltzer *et al*., 2001). A major difficulty with the area around China is the limited number of satellite download stations. Other problems arise from the high mountainous terrain and associated precipitation that can produce undesired signals. Figure 3 illustrates an InSAR result for a moderate-sized event in China.

We have completely revised and extended our regionalization of Asia to include southern Asia, northeast Russia, the Aleutian Islands, and Alaska (Figure 4). The principal changes in China were to combine some of the smaller and/or irregular provinces into more geophysically useful regions. The digitized provinces were defined based on the Exxon geologic maps. Our 3-D Asia model will be updated with these provinces using Litho3D and Model3D. Appropriate regional crustal models are inserted into the provinces and the 3SMAC model is used for the mantle.

Our modeling tool has been adapted to allow computation of 3-D travel times from any event to any station with no need to convert the output model to any other format. We have been using a 3-D bending method for computing minimum travel times, based on Steck and Prothero (1991). This code has been modified to perform in a 3-D spherical model, with topography. We have been exploring the validation of one of our *a-priori* models using this technique. The results allow us to explore which parts of any *a priori* model perform better (or worse) than IASPEI91 (or any other model). We have also included a new visualization tool: we can define a great circle transect from one station to any part of the model, and the code generates a 2-D cross-section. An additional, more qualitative assessment tool for validating models is developed using a wave front construction code (Hildebrand *et al*, 1999). This code has been also modified to perform in a 3-D spherical Earth. The wave front is constructed from interpolation of rays calculated via the shooting method.

As part of our regionalization effort, we have performed a literature search to gather velocity models from regional distances around MAKZ, a seismic array near Makanchi. As of this writing, we have compiled roughly 30 velocity models for the Tien Shan, Kazakhstan, and Siberian shield regions. These are being tested against data to determine the best fitting 1-D models. Eight Vp/Vs models have been gathered for eastern Kazakhstan, and these are shown in Figure 5.

To aid in our Asia calibration efforts, we are analyzing Makanchi and Karatau array data for FK performance and azimuth corrections. With only a handful of events analyzed, no major azimuthal perturbations are observed. Figure 6 shows an example of azimuth and slowness determined for an event recorded at MKAR. We have coded up the

pseudo-FK method, and have implemented improvements in both the error calculation as well as the peak energy calculation.

While correction surfaces are being compiled for stations of interest in Asia using NMBK (Schultz *et al*, 1999), we are also looking towards implementing new methods for locating events. Figure 7 shows a comparison between double-difference relocations and EvLoc relocations for an earthquake sequence in Tibet. Methods of optimizing the double difference and related correlation methods for seismic event relocation are being sought.

CONCLUSIONS AND RECOMMENDATIONS

We are making headway in solving the location problem in Asia. The task is a vast one, and a successful program requires the mutual cooperation of the Department of Energy/NNSA and Department of Defense efforts and the Air Force Technical Applications Center, along with universities and private companies. Results presented in this paper are a snapshot of recent progress in some of our research areas and further work will be presented at the 24th Seismic Research Review.

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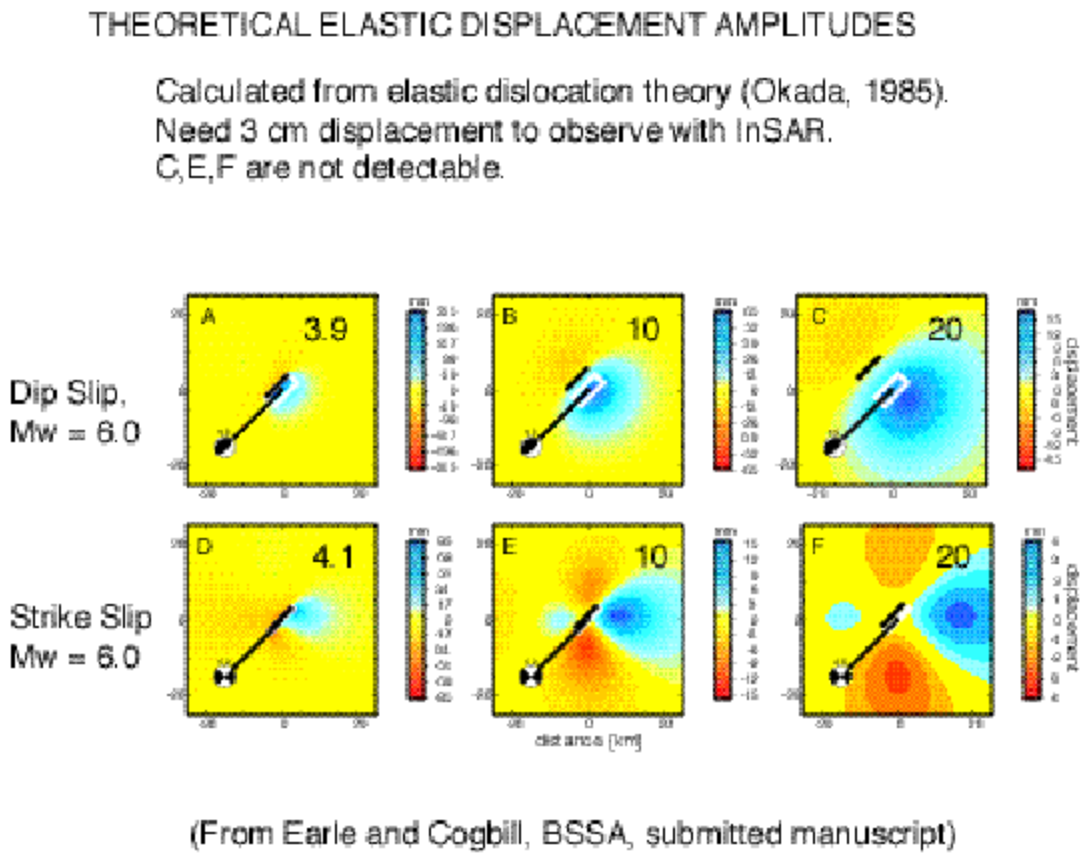

Figure 1. Plot showing theoretical line-of-sight co-seismic surface displacement in millimeters for dip-slip and strike-slip events. The white lines show the surface projection of the square fault planes, and the black lines show the surface trace of the fault. All displacements were calculated for M = 6.0. The centroid depths are A) 3.9 km, B) 10 km, C) 20 km, D) 4.3 km, E) 10 km, and F) 20 km. The dip-slip events (A, B, and C) all have a dip of 67^{o} and the strike-slip events (D, E, and F) have a dip of 85^{o}. The events C, E, and F lie outside the detection threshold.

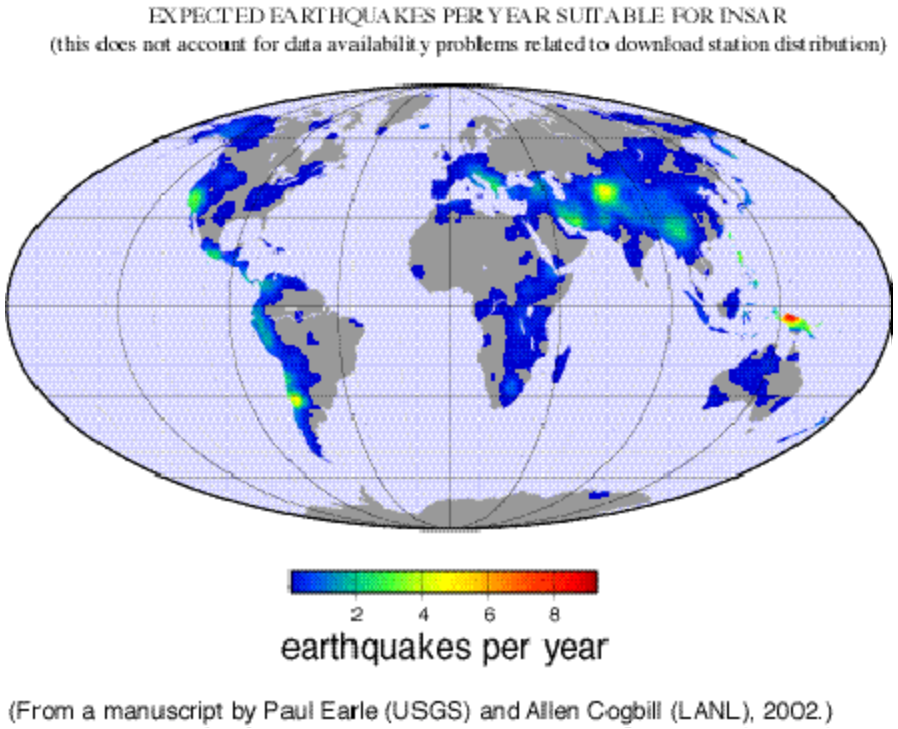

Figure 2. The number of magnitude 5.0 and greater shallow earthquakes occurring per year in a circle of radius 2.5°. The map was generated by calculating earthquake frequency within overlapping 2.5° radius caps and then smoothing the result. The frequency was obtained from 27 years of PDE data.

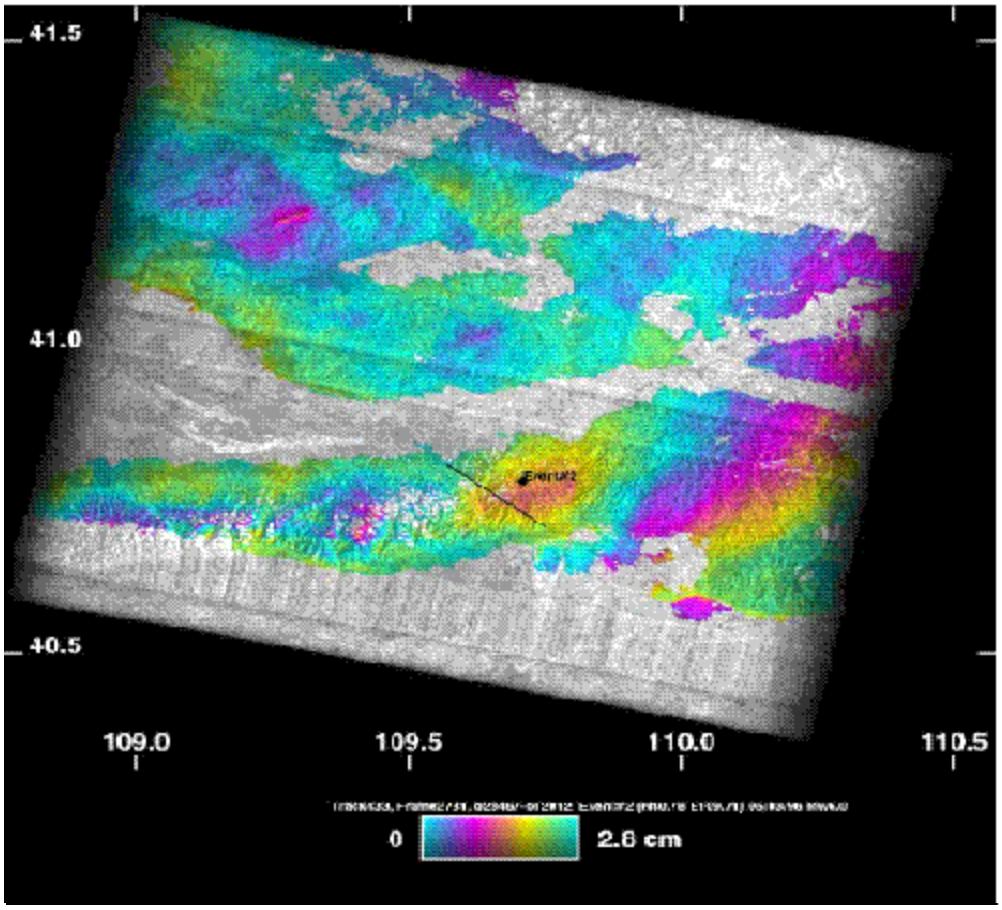

Figure 3. InSAR results for a moderate sized event in China, Mw 6.0. This was deemed a successful result, the only success in attempting to look at three Mw 5-6 events in China.

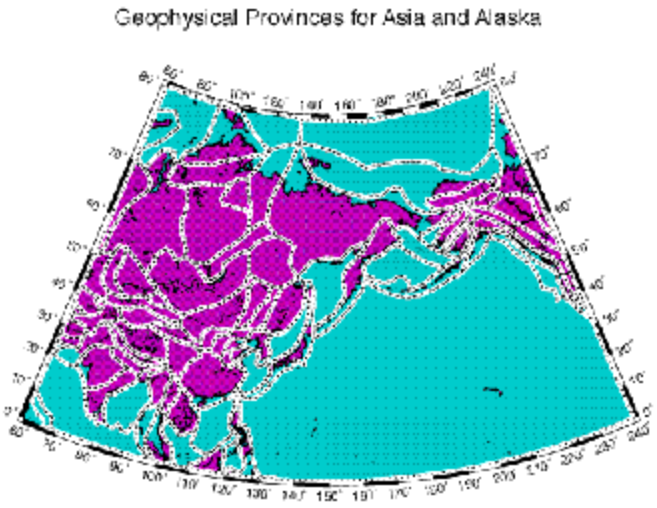

Figure 4. Our newly updated geophysical provinces for Asia and environs.

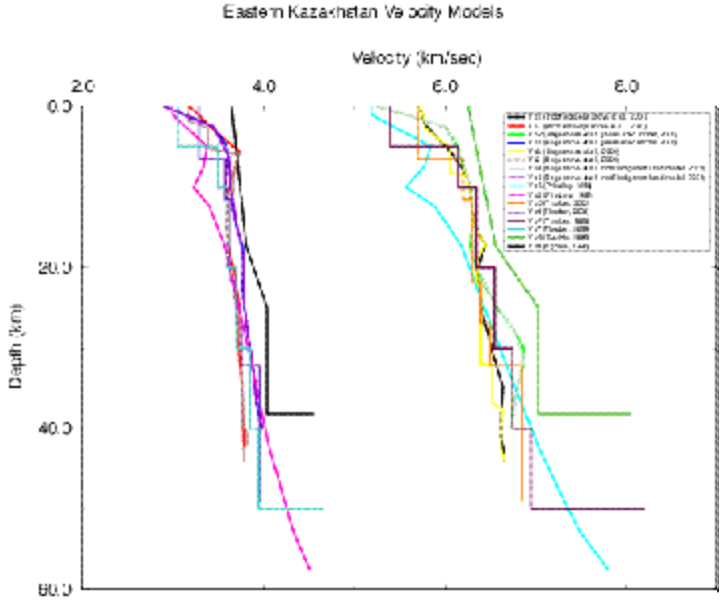

Figure 5. Sample velocity models for eastern Kazakhstan.

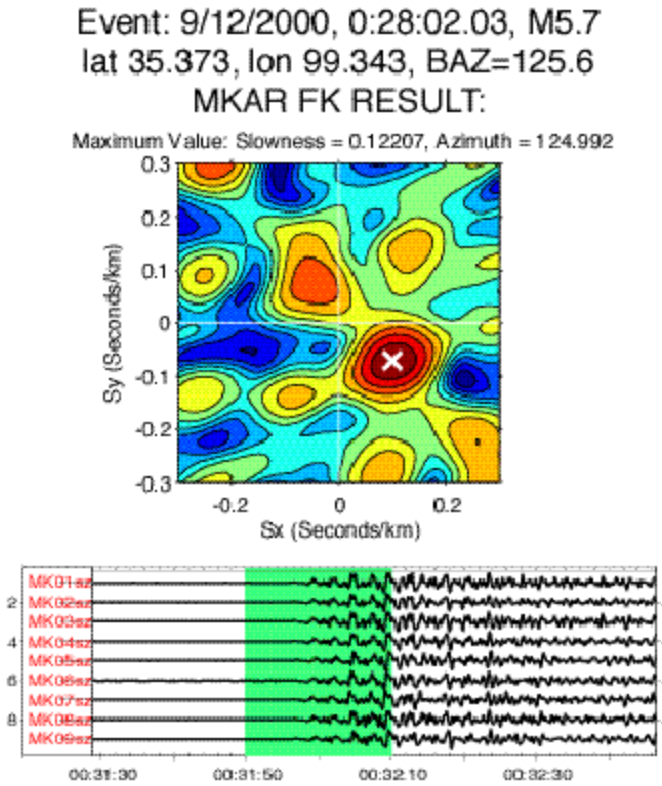

Figure 6. Pseudo FK result for station MKAR.

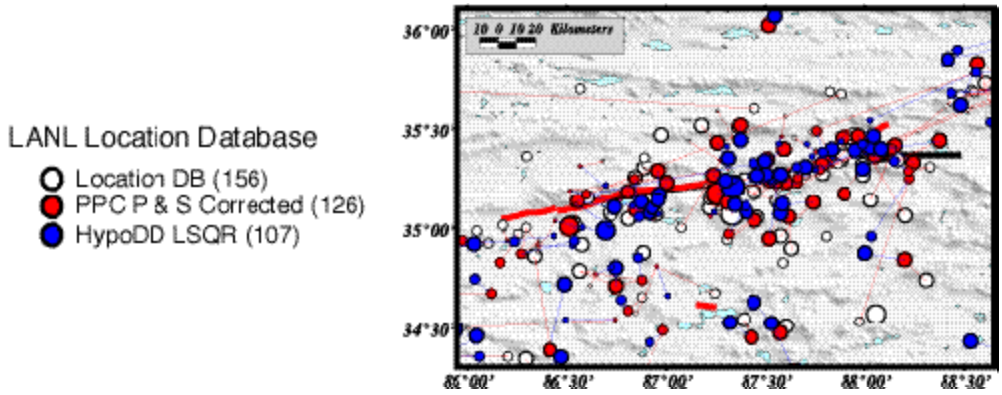

Figure 7. Comparison of EvLoc, EvLoc plus P and S corrections, and Double Difference locations.