SEISMIC LOCATION CALIBRATION FOR 30 IMS STATIONS IN EASTERN ASIA

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Introduction

We review progress of a collaborative academic-industry research consortium comprised of five institutions and led by Lamont, that has started an integrated series of projects, all with the goal of improving the capability to locate seismic events based on data acquired by 30 International Monitoring System (IMS) stations in Eastern Asia.

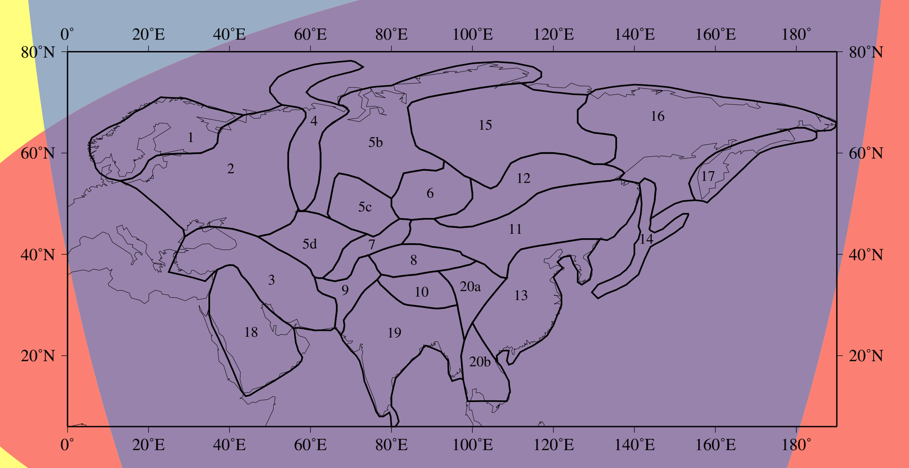
Our general approach has been:

(a) to develop regional models with associated travel times for about 25 sub-regions of Asia,
(b) to compute regional travel times for paths that cross between sub-regions and in this way to model source-specific station corrections (SSSCs) to the IASP91 standard travel times,
(c) to obtain empirical travel times for IMS stations using reference events (ground truth),
(d) to apply kriging methods with model-based SSSCs as background to obtain new SSSCs,
(e) finally we must validate our overall approach. This is the hardest part, and we show preliminary results in this poster. We provide quantitative conclusions (performance metrics) on:

- the degree of improvement in event locations if our SSSCs are used
- the reduction in size of confidence ellipses (by convention, 90% confidence ellipses)
- the coverage of these ellipses (do they contain the right location, 90% of the time?)

A major part of this poster presents the basis for preliminary *Pn* SSSCs at 14 of our 30 IMS stations. These 14 stations are almost all in Russia and Central Asia. A proposal to install these SSSCs in the baseline processing configuration of the Center for Monitoring Research (CMR) was made early this year to the CMR Configuration Control Board. The proposal (1 Mb) and the associated validation test report (7 Mb) may be downloaded from http://www.ldeo.columbia.edu/~richards/consortium.html. Our proposal was accepted in May 2002. The remainder of the poster presents some of the methods we are applying to obtain events of GT5 quality in and near China.

Model



Above is our regionalization of Eurasia. Following an extensive literature search (especially of Russian papers), we developed travel times for the regional seismic waves (*Pg*, *Pn*, *Sn*, *Lg*) for each sub-region. For a path that crosses between two or more sub-regions, we first applied the approximate method of Bondár (1999) to obtain the total traveltime. Working with the University of Connecticut (see their poster 1-06), we have also applied methods of ray computation in 3D structures to obtain regional travel times.

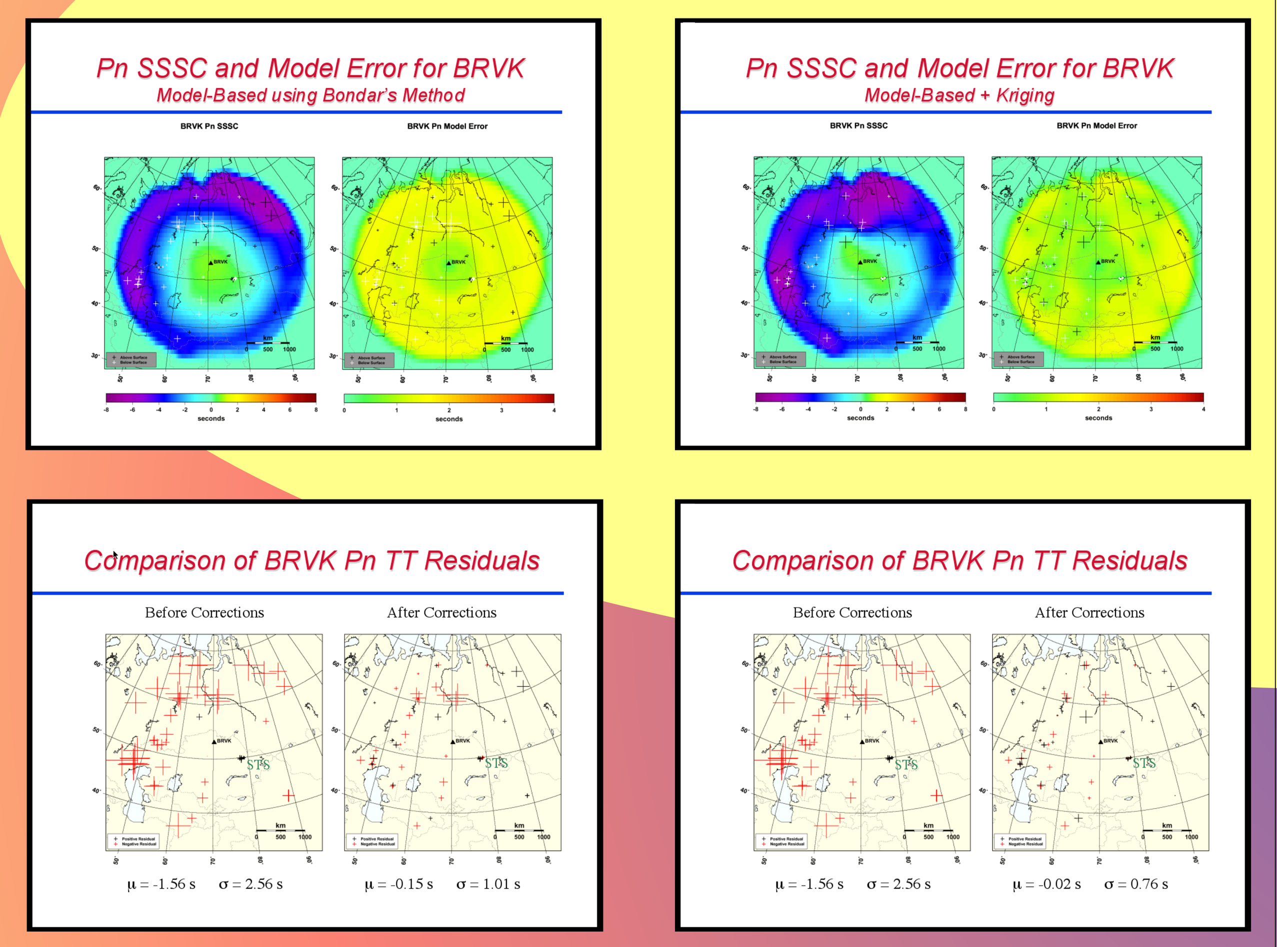
SSSCs

Borovoye (Kazakhstan) probably has the best digital archive* of any seismographic station in the International Monitoring System. In this panel we show the various stages in creating SSSCs. The figures below compare a model-based SSSC for BRVK on the left with a model-based SSSC plus kriging on the right. Kriging reduces bias and scatter in the travel time residuals for the ground truth events. These results are summarized in the table at right.

*http://www.ldeo.columbia.edu/Monitoring/Data/brv_exp_archive.html

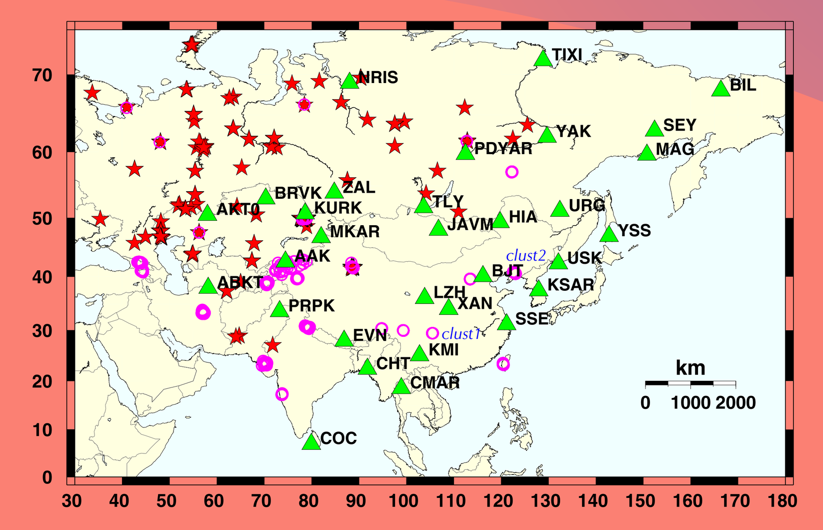
BRVK Pn Travel Time Residuals

Case	IASPEI91		SSSC		SSSC+Kriging	
	$\mu_{\Delta T}$	$\sigma_{\Delta T}$	$\mu_{\Delta T}$	$\sigma_{\Delta T}$	$\mu_{\Delta T}$	$\sigma_{\Delta T}$
STS UNE's	+0.51	0.45	+0.11	0.44	-0.02	0.30
Soviet PNE's	-3.91	1.96	-0.51	1.35	-0.05	1.09
Lop Nor UNE's	-2.52	0.04	0.85	0.04	0.02	0.04
Overall	-1.56	2.56	-0.15	1.01	-0.02	0.76



Kriged SSSCs, on the right, are a significant improvement

Ground Truth



This figure displays the 30 IMS stations in Eastern Asia (green triangles). The red stars indicate previous ground truth data used for calibration and validation of 14 IMS stations in Russia, Mongolia, and Central Asia. For these events (most of which were explosions with locations of GT0 or GT1 quality), we assembled approximately 3000 measurements of *Pn* arrivals. About 85% of these are based on Kitov's dataset of PNE arrivals recorded at stations in and near the former Soviet Union. The magenta circles represent additional ground truth information we are using to calibrate the remaining IMS stations obtained from earthquake relocation believed to be accurate at the GT5 to GT10 level.

Validation

Again, kriged results, on the right, are a signficant improvement

Based on regionalized 1-D travel time models of Eurasia and application of kriging to empirical observations for ground-truth events, we have computed travel times, correction grids relative to IASP91, and modeling errors that allow for lateral variability, and that result in demonstrable improvement in event locations.

For example, we estimated locations of 157 ground truth events (including 82 peaceful nuclear explosions and 77 nuclear explosions at the Semipalatink test site), with and without using the correction grids. **We did this using a "leave one out" approach**, so that each event was relocated using SSSCs that did not use data from that event. We then compared the relocation results to ground-truth locations of these events published by Sultanov et al. (1999).

Our correction grids (SSSCs)

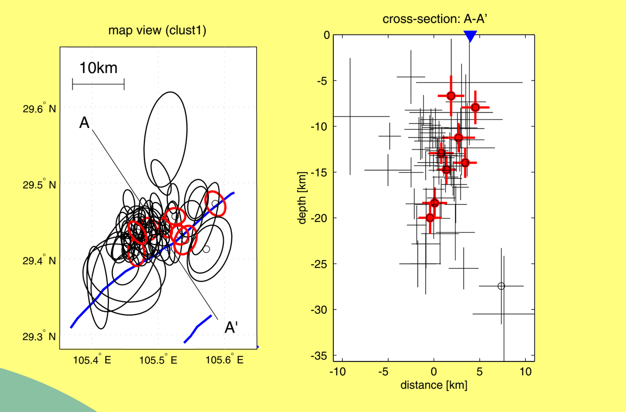
- improved locations for about 93% of the events,
- reduced median mislocation error from 12.2 km to 2.7 km, and
- reduced the median error ellipse size from 1,596 km^2 to 196 km^2, while they
- achieved well over 90% coverage of the ground-truth locations with the error ellipses .

We have obtained similar location improvements using correction grids for five nuclear explosions since 1994 at the Lop Nor test site and seven chemical calibration shots since 1997 at the Semipalatink test site. We plan to make these travel-time grids available for use at the International Data Centre of the Comprehensive Nuclear-Test-Ban Treaty Organization.

Ground Truth in China

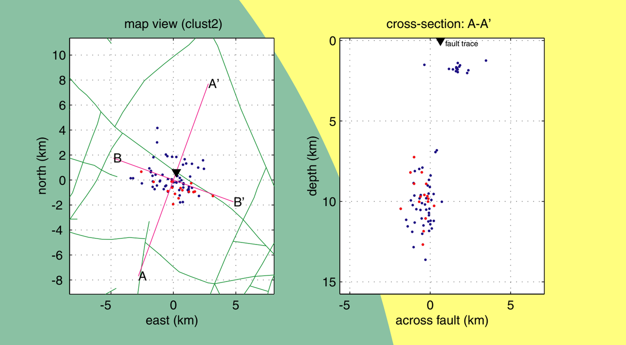
Event locations of GT5 quality were determined by relocating earthquakes using *P*- and *S*-phases from the Annual Bulletin of Chinese Earthquakes (ABCE) and associating the seismicity with surface traces from a digital fault map of China (GPH, USGS). 36 clusters of 20 to 344 earthquakes were formed from about 10,000 events and analyzed with the double-difference technique to obtain precise relative locations. In most cases, a clear seismicity structure can not be resolved, or the mapped seismicity does not correlate with any fault at the surface to provide reliable absolute locations. But some clusters can be tied to surface information. At right an example cluster is shown with 90% confidence ellipses determined by bootstrapping the residual vector. GT5 events (in red) are selected within the cluster based on larger magnitudes, small relative location errors, their stability during the inversion, and their correlation with surface structures.

Regional



In a few cases, we have access to earthquake locations obtained using local network data and the double-difference technique. At right are 74 relocated events in Xiuyan (clust2 on the ground truth figure), received from researchers in China. No error estimates have been provided. Sixteen GT5 events (in red) are selected to have more than 450 P-wave observations each and be greater than *M* 4. Based on the scatter in the locations, observable strike in the seismicity, and association with a nearby surface trace, these events are believed to have better than 5 km accuracy.

Local

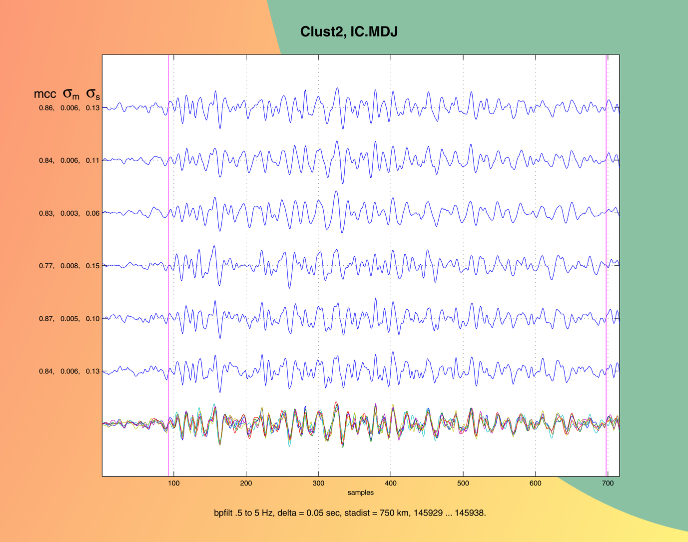


We use the phase data in the ABCE for various regional phases of these events to calibrate IMS stations. At right is a table showing the residuals relative to IASPEI for the Xiuyan cluster (GT5) in the uncorrected column. The mean reflects bias of several seconds, discernible from a few seconds of one sigma scatter. The last two columns show the travel time residuals after a correction surface has been applied which removes most of the bias and reduces the scatter. For comparison we list earlier results obtained for BRVK using GT0 and GT1 explosions.

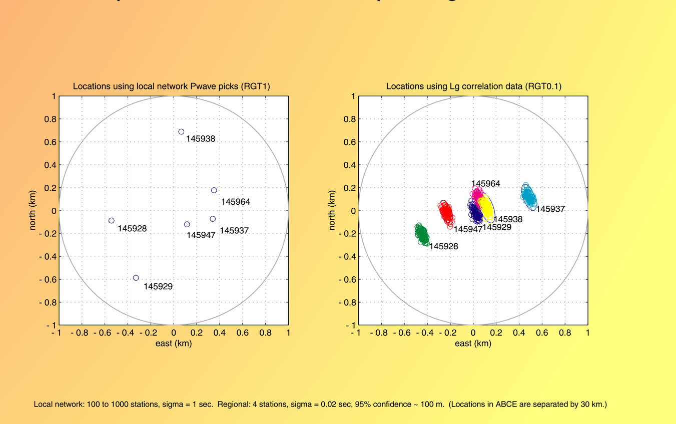
Table 2: Mean and standard deviation of travel time residuals in seconds

	uncorrected		corrected	
phase	μ	σ	μ	σ
P	3.1	2.5	0.7	1.5
Pg	-2.5	2.5	- 0.3	1.5
Pn	2.3	2.0	0.3	1.5
Sg	-7.1	3.7	0	1.5
Sn	0.4	5.4	0.6	3.0
BRVK	IASPEI		SSSC+Kriging	
Pn	-1.56	2.56	-0.02	0.76

Cross Correlation



Comparison of local network and sparse regional locations



In some cases GT5 and GT10 events may not be suitable for calibration of IMS stations especially if the travel times of the region are not that substantially different from IASPEI. Our previous work demonstrated useful results using only explosion data at the GT0 or GT1 level. For most of China, however, this information is not available. We therefore seek ways to achieve better location accuracy for earthquakes in China using available data. Waveform cross correlation has the potential to greatly improve arrival time measurement precision if the seismograms of nearby events are similar. We use data for CDSN stations archived at IRIS for the Xiuyan cluster above to determine if this method can provide added improvement. We observe that for subsets of these clusters the *Lg* waves show good correlation over long windows on the order of 25 seconds, shown at left. The delay measurements have a high degree of internal consistency (measurement residuals are estimated at 7 ms (σ_m) or about a tenth of the sample rate). We solve simple double-difference equations for the epicenter assuming straight ray paths and a velocity of 3.5 km/s. Relative locations using only *Lg* correlation data at four stations are shown at left. Formal errors are shown at 95% confidence along with bootstrap error scatter plots for each event. Semi-major and semi-minor axes average 100 m and 50 m respectively. Location residuals are 0.02 sec. For comparison we show the corresponding local network locations using only *P*-wave picks at several hundred stations. The relative location precision appears to be better than 1 km.