A subjective overview of 24 papers on

Seismic Detection and Location

Ponte Vedra
September 19, 2002

in 20 minutes ? We'll see.

“The overview of the subject matter should be from the unique perspective of you the speaker using session posters to illustrate the points.

…the presentation should not be a straight summary of all the posters in the session.

…[it] should be viewed as an opportunity for you the speaker to describe your own thoughts about the current state of the art and what the issues are for the future.”

OK, so it’s a green light for idiosyncrasies. This could get me in trouble. Why did I accept such an impossible assignment?

OK:

What is the current state of the art?

Deplorable

(Can everybody read these graphics? What exactly is deplorable?)

Specifically, it is deplorable that the seismological community places great reliance upon global bulletins which are produced essentially in the same way that they were produced more than 60 years ago

Forget the improvements in data quality (BB, dynamic range, …), data quantity, and (often) ease of data access

Typically, the seismological community appears more-or-less satisfied to rely upon global or wide-area bulletins that

- locate events one at a time,
- with voluntarily contributed phase picks (NEIC, ISC),
- in the Jeffreys-Bullen Earth model (NEIC, ISC) or some other.

Note that whenever we have achieved orders-of-magnitude improvement in the accuracy of event locations over a wide-area, we have gained new insight into earthquake physics, and/or new insight into Earth structure and processes.

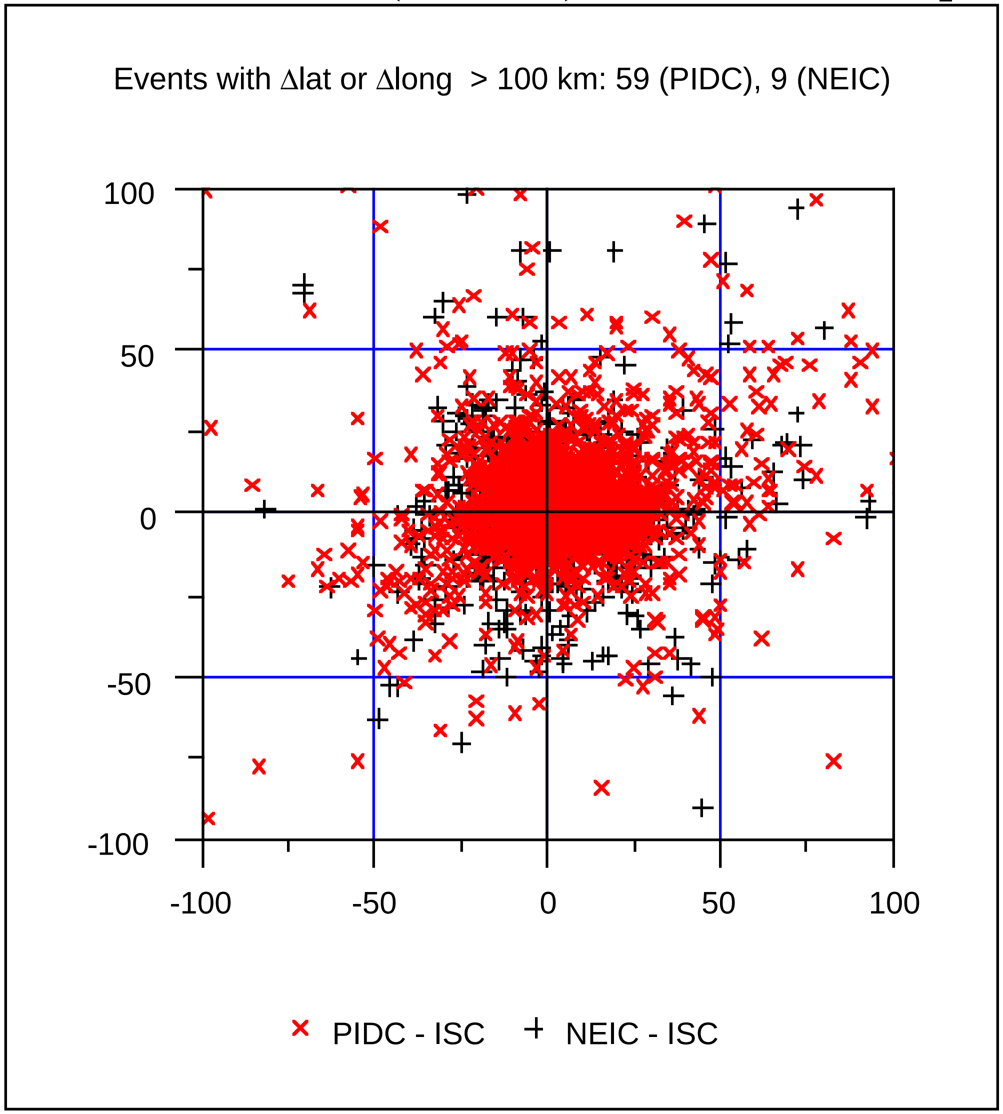
Yes, the REB is different:

- it comes out more promptly (but few people can now see it)
- it has the potential to supply more accurate locations than at present, because of

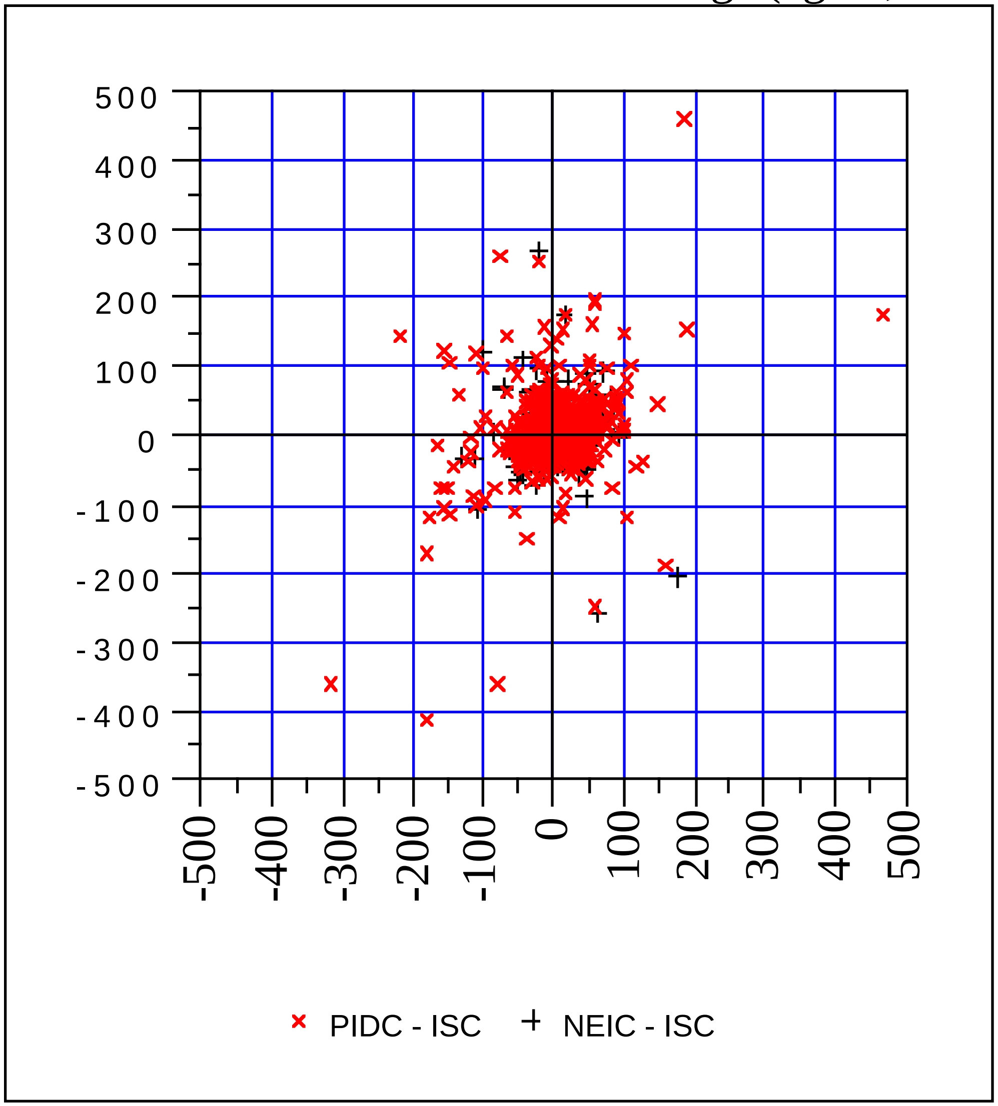
    uniform instrumentation,
    sensitive stations (arrays),
    trained analysts making picks at a single facility (IDC)

But at present, the REB is **worse** (for locations) than NEIC and ISC:

2037 events in REB, NEIC (USGS), ISC for last quarter of 1999:



Changing the scale to ± 500 km to include some real dogs (again, 2037 events, 1997, q4):



[this is routine processing -- don't mis-use these results --we do much better with special analyses of problem events]

24 papers on Seismic Event Detection and Location, sorted into five groups:

(7 papers)
Location capabilities for very broad regions:

(5 papers)
Locations (detection) capabilities for smaller regions

(3 papers)
Detection and/or use of secondary arrivals (for location)

(2 papers)
Software tools

(7 papers)
Methods of analysis

Location capabilities for very broad regions:

2-01 3B Armbruster, J., V. Burlacu, M. Fisk, V. Khalturin, W. Kim, I. Morozov, E. Morozova, P. Richards, D. Schaff, F. Waldhauser
Seismic Location Calibration for Thirty International Monitoring System Stations in Eastern Asia

2-04 3B Bondar, I., K. McLaughlin, X. Yang, J. Bhattacharyya, H. Israelsson, R. North, V. Kirichenko, R. Engdahl, M. Ritzwoller, A. Levshin, N. Shapiro, E. Bergman, M. Antolik, A. Dziewonski, G. Ekström, H. Ghalib, I. Gupta, R. Wagner, W. Chan, W. Rivers, A. Hofstetter, A. Shapira, G. Laske
Seismic Location Calibration in the Mediterranean, North Africa, Middle East and Western Eurasia

2-05 3B Engdahl, E., E. Bergman, M. Ritzwoller, N. Shapiro, A. Levshin
A Reference Data Set for Validating 3-D Models

2-12 3C Murphy, J., W. Rodi, M. Johnson, J. Sultanov, T. Bennett, M. Toksöz, C. Vincent, V. Ovtchinnikow, B. Barker, A. Rosca, Y. Shchukin
Seismic Calibration of Group 1 International Monitoring System (IMS) Stations in Eastern Asia for Improved Event Location

2-13 3C Myers, S., M. Flanagan, M. Pasyanos, C. Schultz
Location Calibration in Western Eurasia and North Africa: Ground Truth Improved Earth Models, Bayesian Kriging, Regional Analysis, Location Algorithms, Array Calibration, and Validation

2-22 3C Steck, L., H. Hartse, C. Bradley, C. Aprea, A. Velasco, G. Randall, J. Franks
Regional Location Calibration in Asia

2-24 3C Wallace, T., F. Vernon, G. Pavlis
Collaborative Research: Seismic Catalogue Completeness and Accuracy (all this in 20 minutes?)

Locations (detection) capabilities for smaller regions

2-06 3B Gitterman, Y., V. Pinsky, A. Shapira, M. Ergin, D. Kalafat, C. Gürbüz, K. Solomi
Improvement in Detection, Location, and Identification of Small Events Through Joint Data Analysis by Seismic Stations in the Middle East/Eastern Mediterranean Region

2-09 3B Kohl, B., R. North, J. Murphy, M. Fisk, G. Beall
Demonstration of Advanced Concepts for Nuclear Test Monitoring Applied to the Nuclear Test Site at Lop Nor, China

2-14 3C Nyblade, A., R. Brazier, C. Schultz, M. Pasyanos
Ground Truth Events from Regional Seismic Networks in Northeastern Africa

2-17 3C Ringdal, F., T. Kvaerna, E. Kremenetskaya, V. Asming, C. Lindholm, J. Schweitzer
Research in Regional Seismic Monitoring

2-20 3B Saikia, C., H. Thio, G. Ichinose, B. Woods
Regional Wave Propagation and Influence of Model-Based and Empirical SSSCs on Locations In and Around The Indian Subcontinent

Detection and/or use of secondary arrivals (for location)

2-03 3B Bergman, E., E. Engdahl
Probability Density Functions for Secondary Seismic Phase Arrivals

2-08 3B Husebye, E., Y. Fedorenko, E. Beketova
Enhanced CTBT Monitoring Through Modeling, Processing and Extraction of Secondary Phase Information at High Signal Frequencies

2-16 3C Reiter, D., J. Bonner, C. Vincent, J. Britton
Incorporating Secondary Phases in 3D Regional Seismic Event Location: Application to the Sparse Network Problem

Software tools

2-07 3B Hipp, J., R. Simons, L. Jensen, L. Lindsey, M. Chown
The GNEM R&E Parametric Grid Software Suite: Tools for Data Creation, Access, Management, Viewing, and Export

2-11 3C Merchant, B., J. Drake, D. Hart, C. Young
Multiple Algorithm Signal Detection Using Neural Networks

Methods of analysis

2-02 3B Ballard, S., P. Reeves
Improved Seismic Event Location Resolution Using a Damped Least Squares Algorithm

2-10 3B Mamsurov, M., V. Kovalenko
Permissible Spatio-Temporal Errors of Seismic Event Location Accuracy in the Context of Nuclear-Explosion-Monitoring Requirements

2-15 3C Randall, G., H. Hartse, L. Steck
Attempts to Enhance Array Detection Capability: A Search for Systematic Array Residuals

2-18 3B Rodi, W., C. Schultz, W. Hanley, S. Sarkar, S. Kuleli
Grid-Search Location Methods for Ground-Truth Collection from Local and Regional Seismic Networks

2-19 3C Rodi, W., R. Engdahl, E. Bergman, F. Waldhauser, G. Pavlis, H. Israelsson, J. Dewey, N. Toksöz
A New Grid-Search Multiple-Event Location Algorithm and a Comparison of Methods

2-21 3C Saikia, C., R. Lohman, G. Ichinose, D. Helmberger, M. Simons, P. Rosen
Ground Truth Locations - A Synergy of Seismic and Synthetic Aperture Radar Interferometric Methods

2-23 3C Thurber, C., H. Zhang, C. Rowe, W. Lutter
Methods For Improving Seismic Event Location Processing

2-01 3B Armbruster, J., V. Burlacu, M. Fisk, V. Khalturin, W. Kim, I. Morozov, E. Morozova, P. Richards, D. Schaff, F. Waldhauser
Seismic Location Calibration for Thirty International Monitoring System Stations in Eastern Asia

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Collaborative Research: Seismic Catalogue Completeness and Accuracy

These groups have adopted somewhat different approaches.

The overall plan of the Lamont-led consortium has been:

(a) to develop regional models with their associated travel times for about 25 sub-regions of East Asia;

(b) to compute regional travel times for paths that cross between sub-regions and thus to obtain model-based SSSCs;

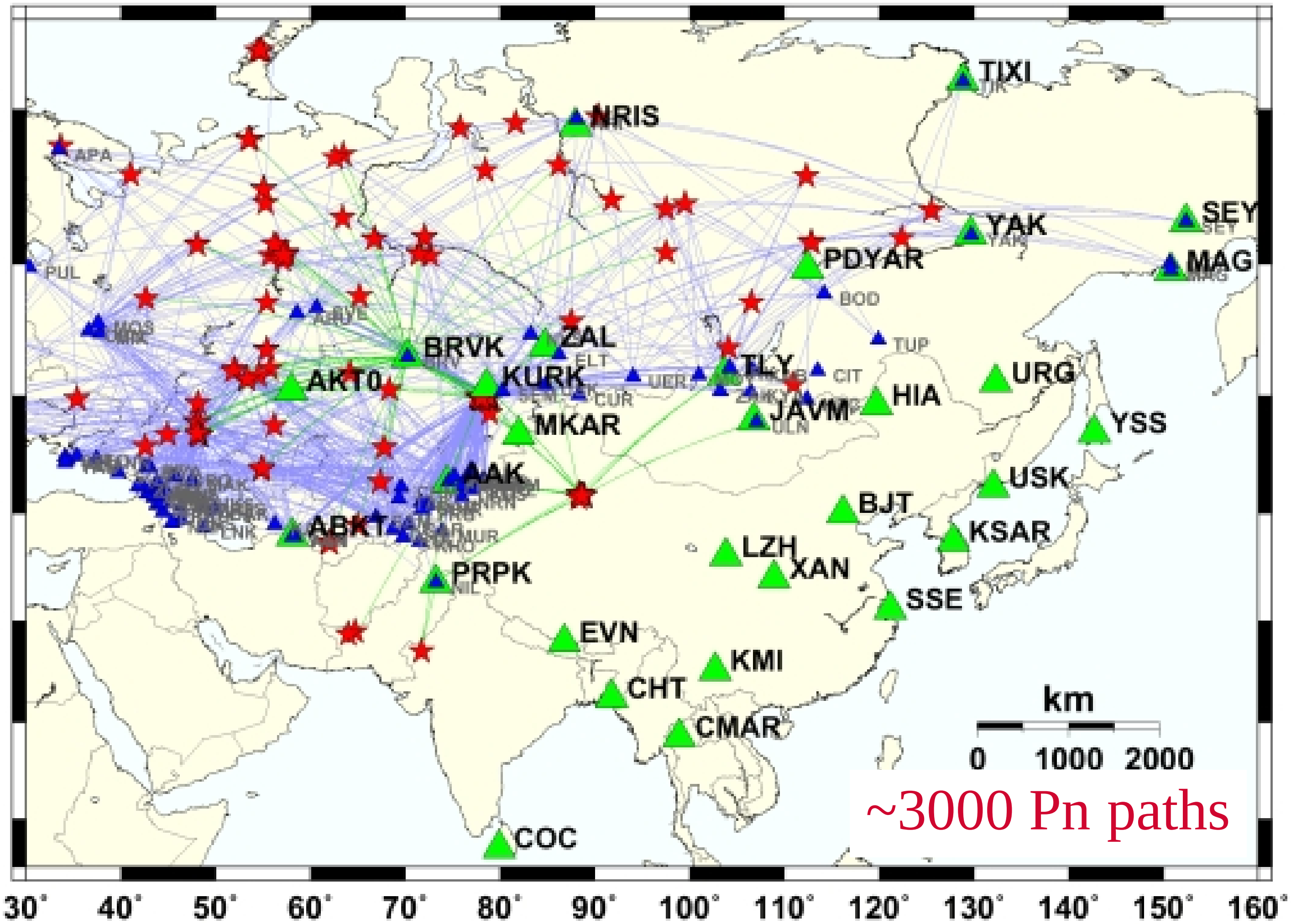
(c) to obtain empirical travel times for IMS stations (or their surrogates), using reference events (GT);

(d) to apply kriging methods (with the model-based SSSCs as background) to obtain new SSSCs.

Then

(e) there is the final work of assessing relocation performance, which again uses ground truth, and sampling methods (leave-one-out, etc.) to avoid using data twice. (Don’t relocate an event that was used to develop the travel time model.)

This last step is the hardest. We are only beginning to take it.



174 GT explosions (stars) and the recording seismographic stations (triangles) used for validation tests. Good news, bad news: dense regions, blank regions (but, with earthquakes)

Use of kriged SSSCs, for 14 IMS stations in Russia and Central Asia, has led us to the following preliminary results:

- median mislocation error reduced from 12.2 km to 2.7 km,
- error ellipse areas reduced by 20% or more for 97% of events,
- median error ellipse reduced from 1,596 to 196 km^2, while achieving 100% coverage.

SAIC/MENA consortium (McLaughlin et al.):

"The project is in its second and final phase. In Phase 1 we demonstrated that significant improvements are achieved by using travel-time correction surfaces generated from global 3-D models. Improved velocity models have reduced a priori travel-time variances by 50% while maintaining 90% coverage. In Phase 2 improved 3D global models, such as the CUB2.0 (Shapiro et al, 2002) and the PS362 (Antolik et al, 2002) are employed to generate travel-time correction surfaces via ray-tracing. The CUB2.0 model, a global upper mantle model combined with the CRUST2.0 crustal model (Bassin et al, 2000), is used to generate correction surfaces for regional phases. For teleseismic travel-time correction surfaces, we employ the PS362 global whole mantle model where the crust is taken into account as a crustal correction derived from CRUST2.0."

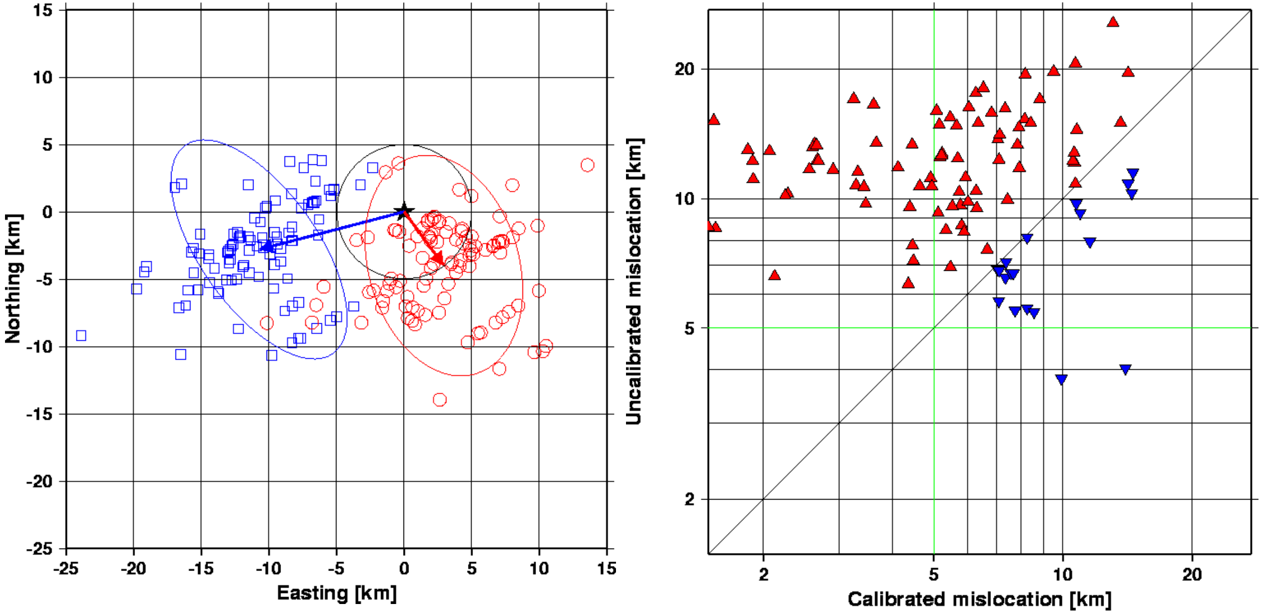


Figure 9. Relocation study of a GT5 event from the Hoceima, Morocco, cluster with sparse, random subsets of stations. Each random subnetwork is unique and has 6-10 stations with an azimuthal gap less than 130° and a secondary gap less than 160°. (a) Calibrated (circles) and uncalibrated (squares) locations relative to GT. The mean bias vectors together with their error ellipse are also shown. (b) Scatter plot of mislocations, points above the diagonal indicate improvements. Eighty per cent of the events were improved due to calibrated travel times, resulting in a 55% reduction in bias.

“Improved selection criteria for candidate GT5 events at the 95% confidence level have been established and validated using GT0 explosions (Bondár et al, 2002a; Bondár et al, 2002b).
GT5 @ 95% confidence requires that an event be located with

- at least 10 stations within 250 km with an azimuthal gap less than 110° and a secondary azimuthal gap less than 160°
- at least one station within 30 km from the epicenter

The latter constraint gives some confidence in depth. For the [event to be big enough to be useful] we also require that events be recorded beyond 250 km.”

SAIC/East Asia consortium (Murphy et al)

"... we have formulated and implemented a sophisticated, fully nonlinear tomographic inversion algorithm and applied it to the refinement of our velocity models of the Former Soviet Union (FSU) DSS region and the India/Pakistan region (WINPAK3D).

… we have concluded that our current DSS and WINPAK3D velocity models are essentially final. P wave SSSC estimates, based on our revised velocity model of the Group 1 region, have now been estimated for all 30 Group 1 station locations"

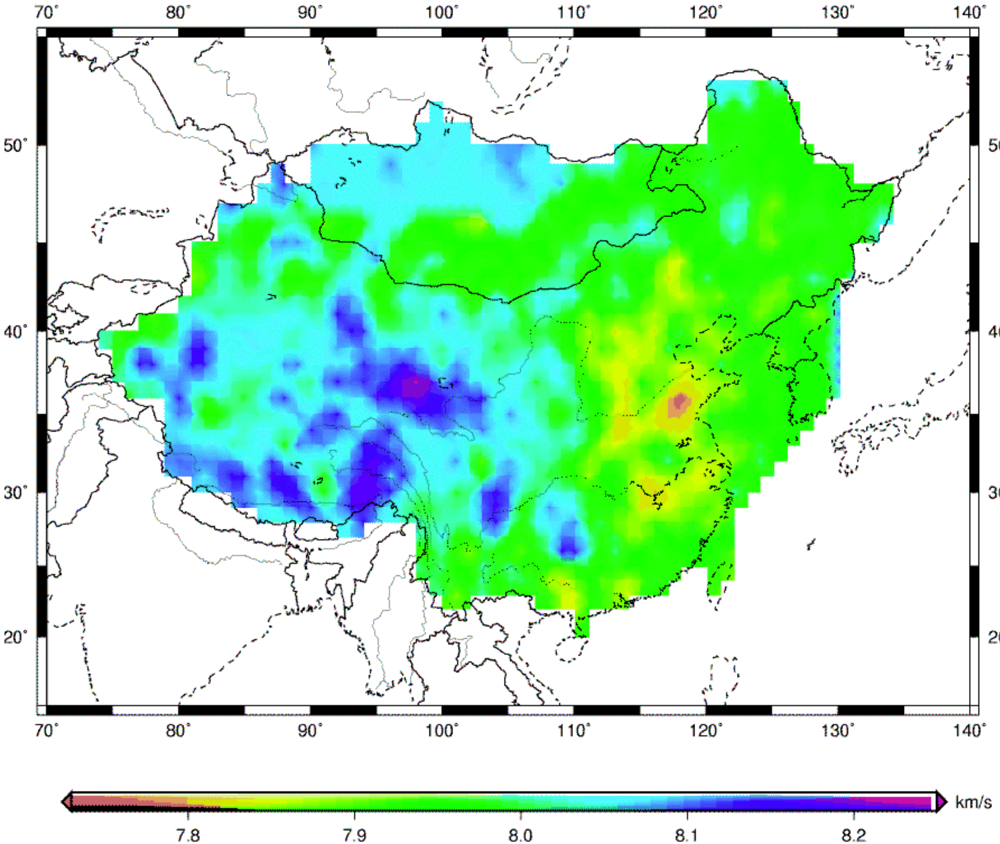


Figure 3. Pn upper mantle velocities for China/Mongolia derived from inversion of Chinese Bulletin earthquake data.

The title and authors of the main LLNL paper (2–13):

LOCATION CALIBRATION IN WESTERN EURASIA AND NORTH AFRICA: GROUND TRUTH, IMPROVED EARTH MODELS, BAYESIAN KRIGING, REGIONAL ANALYSIS, LOCATION ALGORITHMS, ARRAY CALIBRATION, AND VALIDATION

Stephen C. Myers, Megan Flanagan, Michael Pasyanos, William Walter, Paul Vincent, and Craig Schultz

Begs the question: is “location calibration” supposed to be “rocket science,” or should it be simple work, done carefully and well?

Answer: It has to be both (despite the views of Lord Rutherford …).

In addition to

GROUND TRUTH, IMPROVED EARTH MODELS, BAYESIAN KRIGING, REGIONAL ANALYSIS, LOCATION ALGORITHMS, ARRAY CALIBRATION, AND VALIDATION

we need to know (for example) where to find the excruciating details of what station coordinates to use, for data purportedly from "Norilsk" and Magadan" stations … and many other such details.

The latter is not rocket science. It is still essential, to getting best results.

There are papers in these sessions, reporting the accumulation of millions of phase picks.

OK. But, if the job can be done with orders-of-magnitude smaller datasets of high quality, I'd be cautious here. Just as it makes sense to avoid clogging up databases with GT10 (and worse) reference events, in regions where better quality (e.g. GT5) can be found, so it makes sense to avoid ray paths where there is uncertainty about clock corrections, station coordinates, and source location. (Unless there is nothing better.)

(Dusty Rose = Richards' prejudice)

What has been learned?
There is some bad news, and some good news:

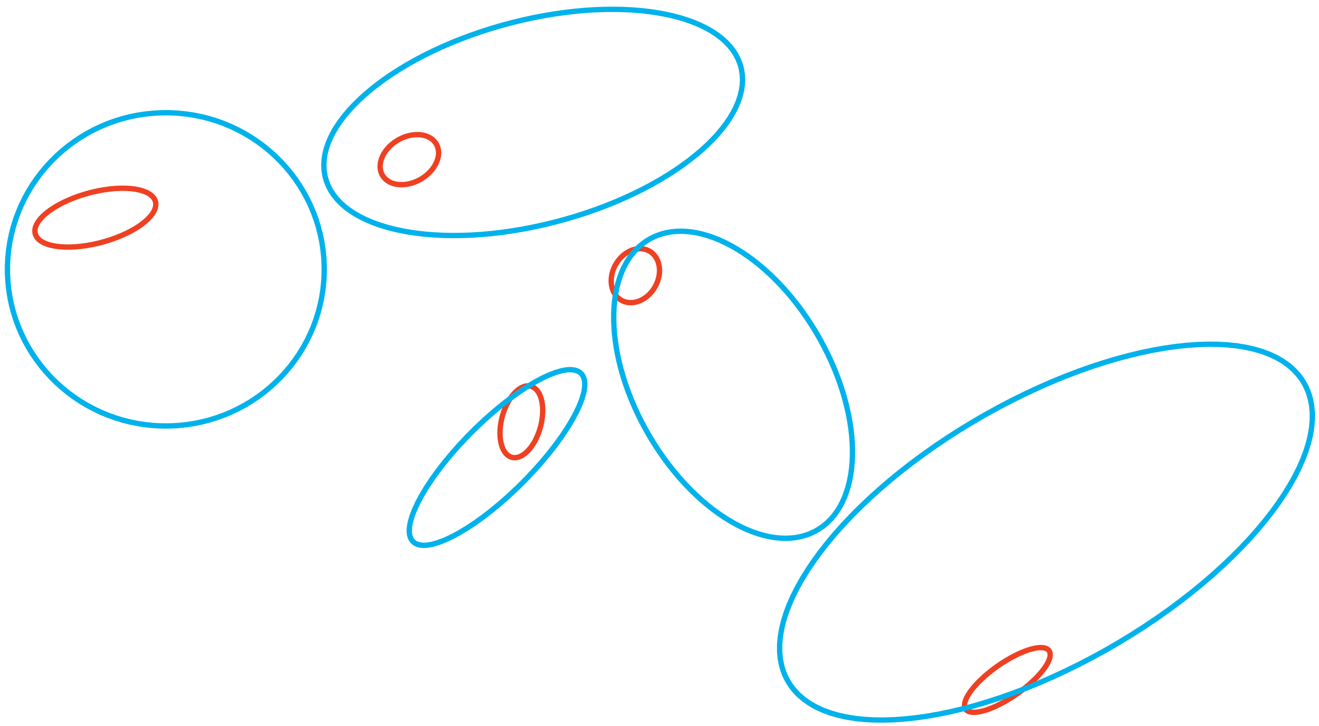
1. It's much harder than the community thinks, to achieve GT5 quality for absolute locations. (Most of us have long been uncritical. Taiwan and Japan are the world leaders. Maybe, only these countries achieve this quality routinely in national bulletins.)

2. GT5 quality can be achieved for some events over broad regions, such as much of China. (But, this requires special studies, such as multiple event location algorithms applied to groomed data.) We need to build up high quality GT – even better than GT5, wherever possible.

3. High quality GT is needed — otherwise, we cannot know when we have reliably better locations. For example, GT10 quality is typically **not good enough** to enable validation of location improvement.

Ground truth information in red

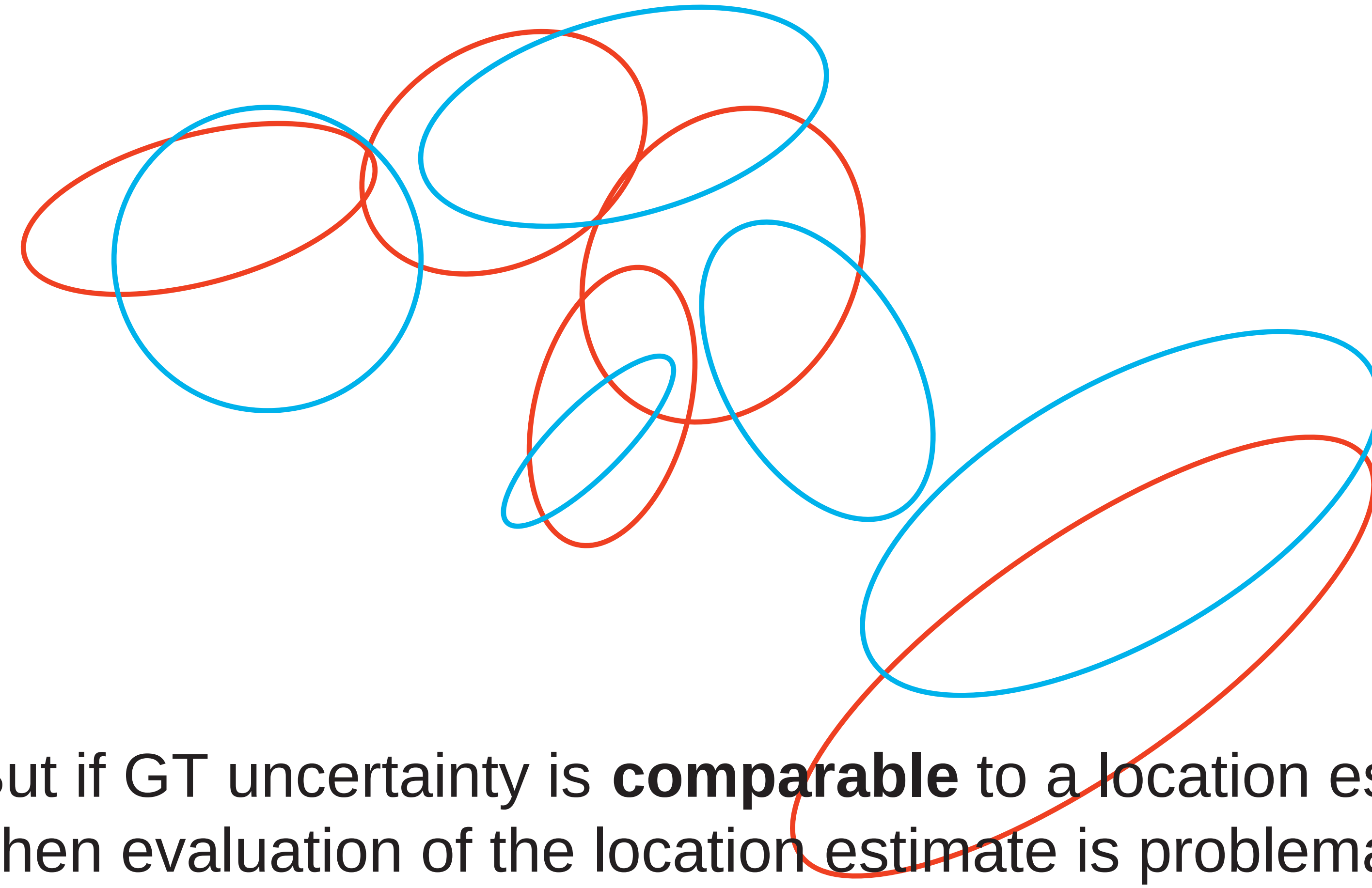
Epicenter estimate in light blue



If GT uncertainty is much smaller than a location confidence interval, then evaluation of the location estimate is straightforward (do the location uncertainties include 90% of GT events?)

Ground truth information in red

Epicenter estimate in light blue



But if GT uncertainty is **comparable** to a location estimate, then evaluation of the location estimate is problematic (euphemism, Pythagoras; worse, Rutherford quote...)

What are the issues for the future
(in seismic location capability)**?**

Note that achievement of more accurate location is of broad interest in scientific studies of the Earth and of earthquake physics, and in mitigation of earthquake hazard.

1. Emphasize superGT. Some of us have been fixated on GT5. But **where we can do even better, we should**. (Preferably **without** re-introduction of nuclear testing.) Establish an international effort (through IASPEI? ISC? NEIC?) to flag/bring out those events for which special information allows much higher quality. (Efforts now are haphazard, or are with agencies that have very limited abilities to acquire information from diverse organizations outside the U.S.). Use

   $S - P$ of a few tenths of a second.
   Local network operations in a well-studied region.
   Mapped surface faulting.
   Synthetic Aperture Radar
   ……

2. Develop/take opportunities for international cooperation with the two most populous countries in the world — in the context of earthquake hazard mitigation, and scientific studies (if not for explosion monitoring). For example, we need to establish an effort to document (certify?) the quality of station locations. (Check station coordinates with GPS receivers.)

3. **To remove pick error, we must make conventional phase picks irrelevant.**

Instead, go with massive waveform databases, and waveform cross-correlation or some type of envelope matching/stretching. The key resource will be long-running stations with archived waveforms that are high-quality/easily accessed.

2-24 3C Wallace, T., F. Vernon, G. Pavlis
Collaborative Research: Seismic Catalogue Completeness and Accuracy

Saudi Arabia to Western China. ~ 25,000 events, 1995 to present.

(I hope they emphasize high quality events.)

These authors claim that:

"Seismic event detection and location are the single most important research issues for adequately monitoring a Comprehensive Nuclear-Test-Ban Treaty (CTBT)."

It all comes down to

"Earthquake
location,
location,
location"