Group-2 Consortium Phase 1 Delivery

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Outline

- Objectives
- Phase 1 delivery:
  - Delivered in October 2001
  - CCB in December 2001
  - Delivery accepted by RDSS in January 2002
- Delivery inventory:
  - Models
  - Data
  - SSSCs
  - Documentation
- Validation testing and evaluation
  - Offline testing
  - Online testing
- Conclusions

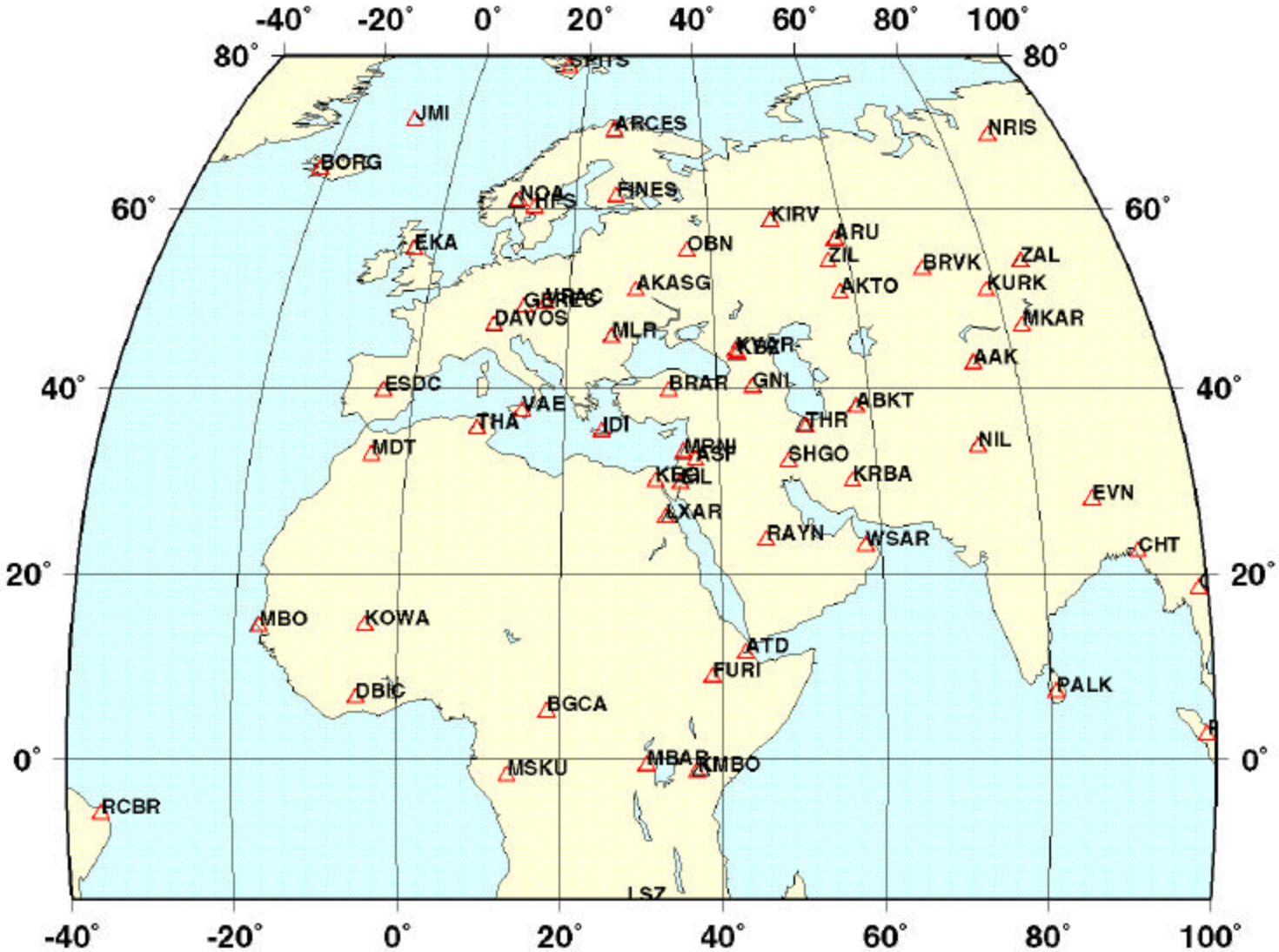
Objectives

- To develop, validate, and deliver preliminary SSSCs:
  - 63 IMS stations, Pn and Sn phases, shallow depth
- Significant improvement on location uncertainty by variance reduction:
  - Smaller error ellipses
  - 90% coverage
- Significant improvement on location accuracy by better regional travel times:
  - Reduction in regional location bias
  - Reduction in misfit
  - Reduction in origin time errors

What Was in Phase 1 Delivery? (http://g2calibration.cmr.gov)

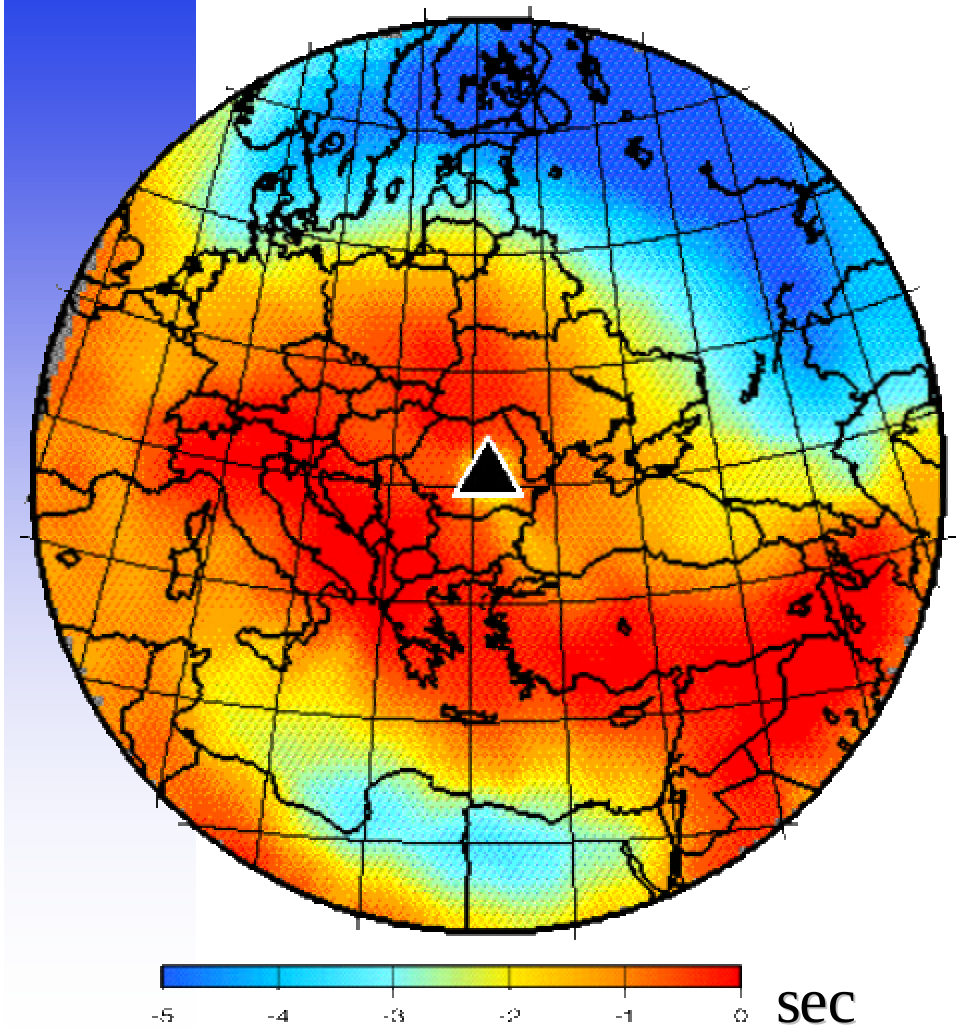
- Two 3D models:
  - CUB1.0 model: global crust and upper mantle models using improved group and phase velocity data sets and inversion
  - SAIC-HRV model: regionalized crusts combined with a 3D mantle model
- Data: Reference Event List 1.1:
  - ~1600 GT0-GT10 events in the Group-2 region
  - ~81,000 regional arrivals
- Preliminary SSSSCs from CUB 1.0:
  - Pn, Sn SSSCs for 10 km of source depth
  - 63 IMS stations in the region of –20-80° N & -40-100° E
  - Out to 20° from each station by raytracing
  - 1°x1° latitude/longitude grid spacing
  - Modeling error estimated from EHB residuals w.r.t. CUB 1.0
  - Validated by empirical path corrections & GT event relocation
  - Tested online in the automatic system and by analysts on RDSS testbed
- Documentation: 20 reports/memos

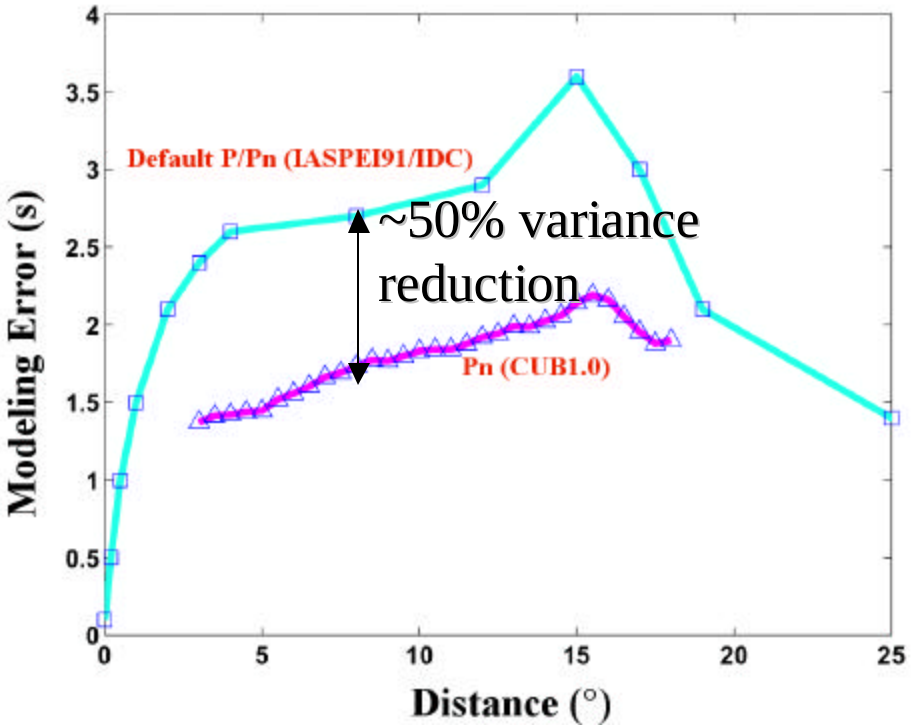
63 IMS stations with Pn & Sn SSSCs Delivered in Phase 1



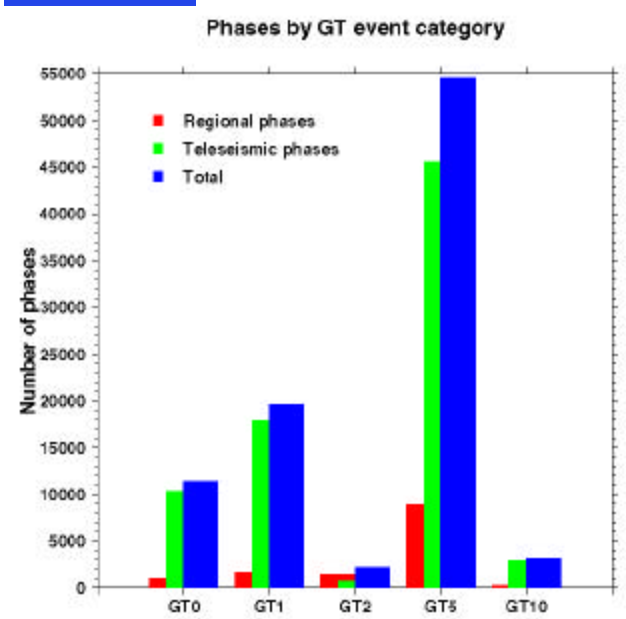
Pn SSSCs & Modeling Errors

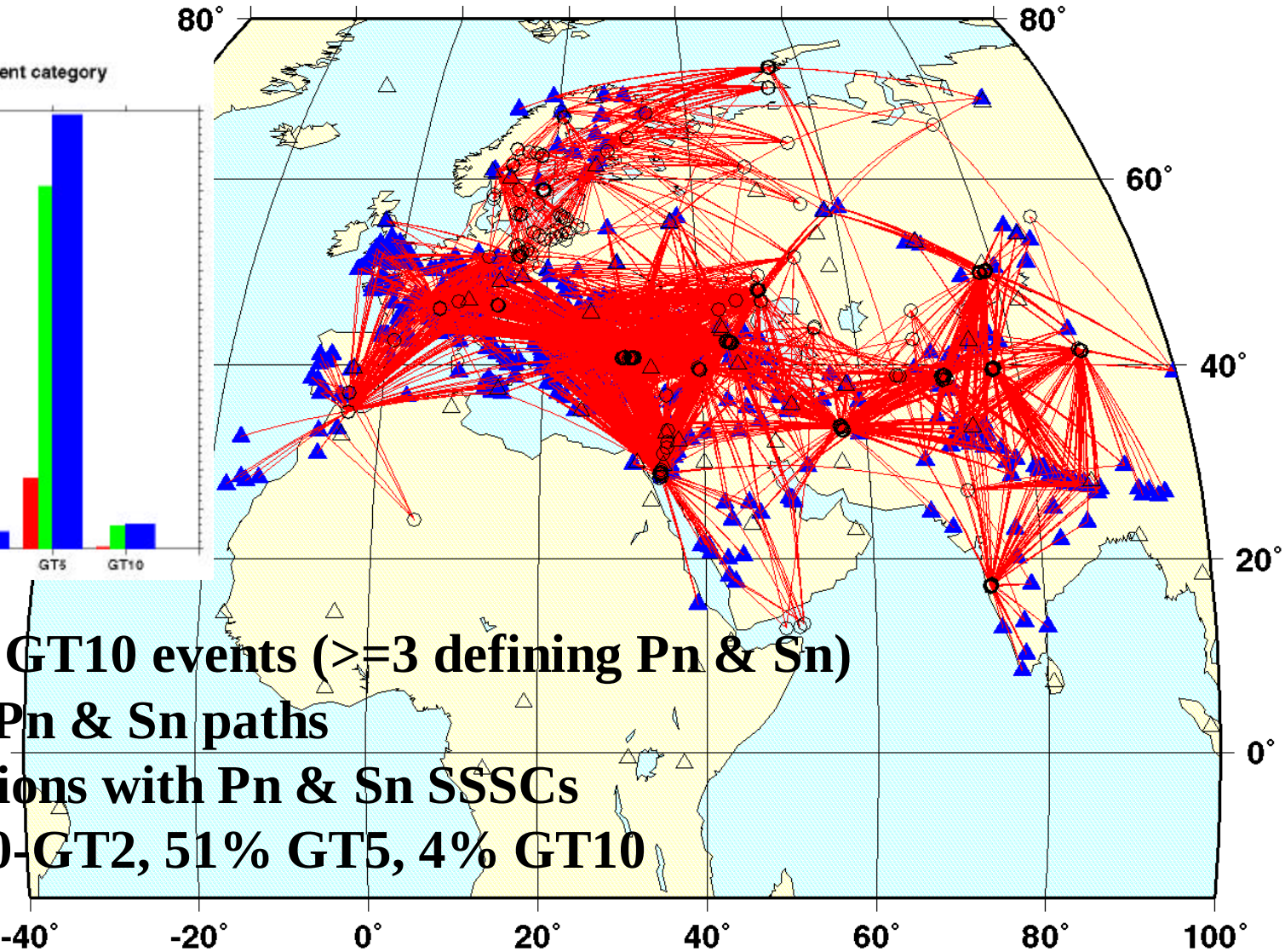
MLR (Muntele Rosu, Romania)





GT Events in REL1.1 Used in Model Validation Relocation Testing





- 571 GT0-GT10 events (>=3 defining Pn & Sn)
- ~ 10,000 Pn & Sn paths
- 1390 stations with Pn & Sn SSSCs
- 45% GT0-GT2, 51% GT5, 4% GT10

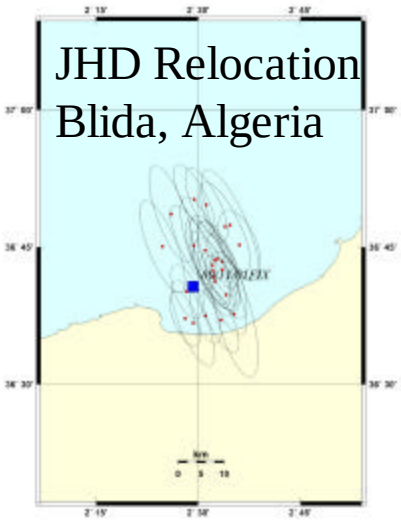
Validation Testing & Evaluation

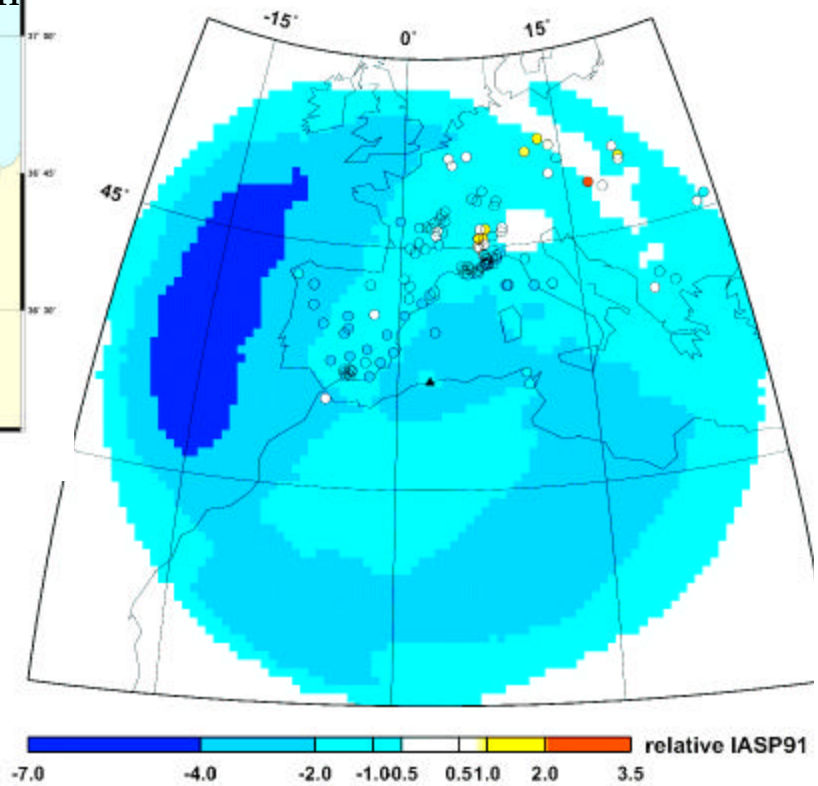
- **Tests:**
  - **To validate SSSCs and model errors by direct comparisons between model-based and empirical path corrections and GT event relocations**
  - **To benchmark 3D SSSCs with existing Fennoscandian 1D SSSCs**
  - **To validate expected improvement in existing and future IMS networks**
- **Evaluation metrics/criteria:**
  - **Comparisons of relocations results with and without SSSCs**
  - **1999 Oslo recommendations**
  - **Additional metrics developed accounting for GT errors**
  - **All locatable events included in evaluation**

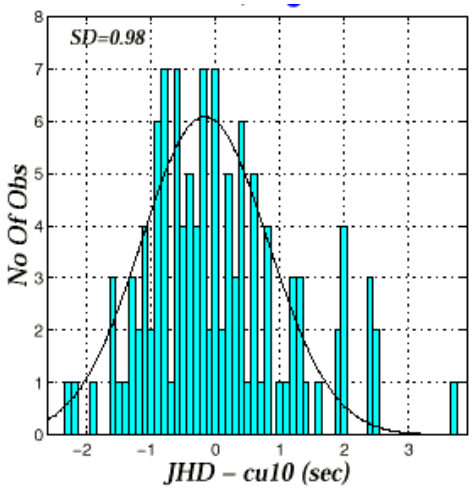
Validation Using Cluster Analysis

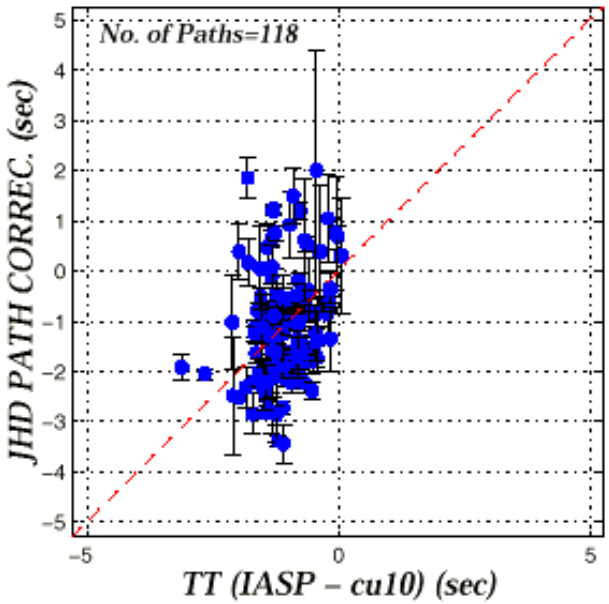
- ~ 4000 empirical JHD P path corrections for 47 event clusters
- Validated SSSCs and model errors:
  - Encouraging agreement between model-based and empirical correction
  - Significant correlation for 37 clusters, consistent with model errors
  - 30% reduction in bulk standard deviation; 44% variance reduction. JHD-SSSCs approximately Gaussian
  - CUB model errors may be conservative
  - Support 1 degree grid spacing

Example of Cluster Analysis









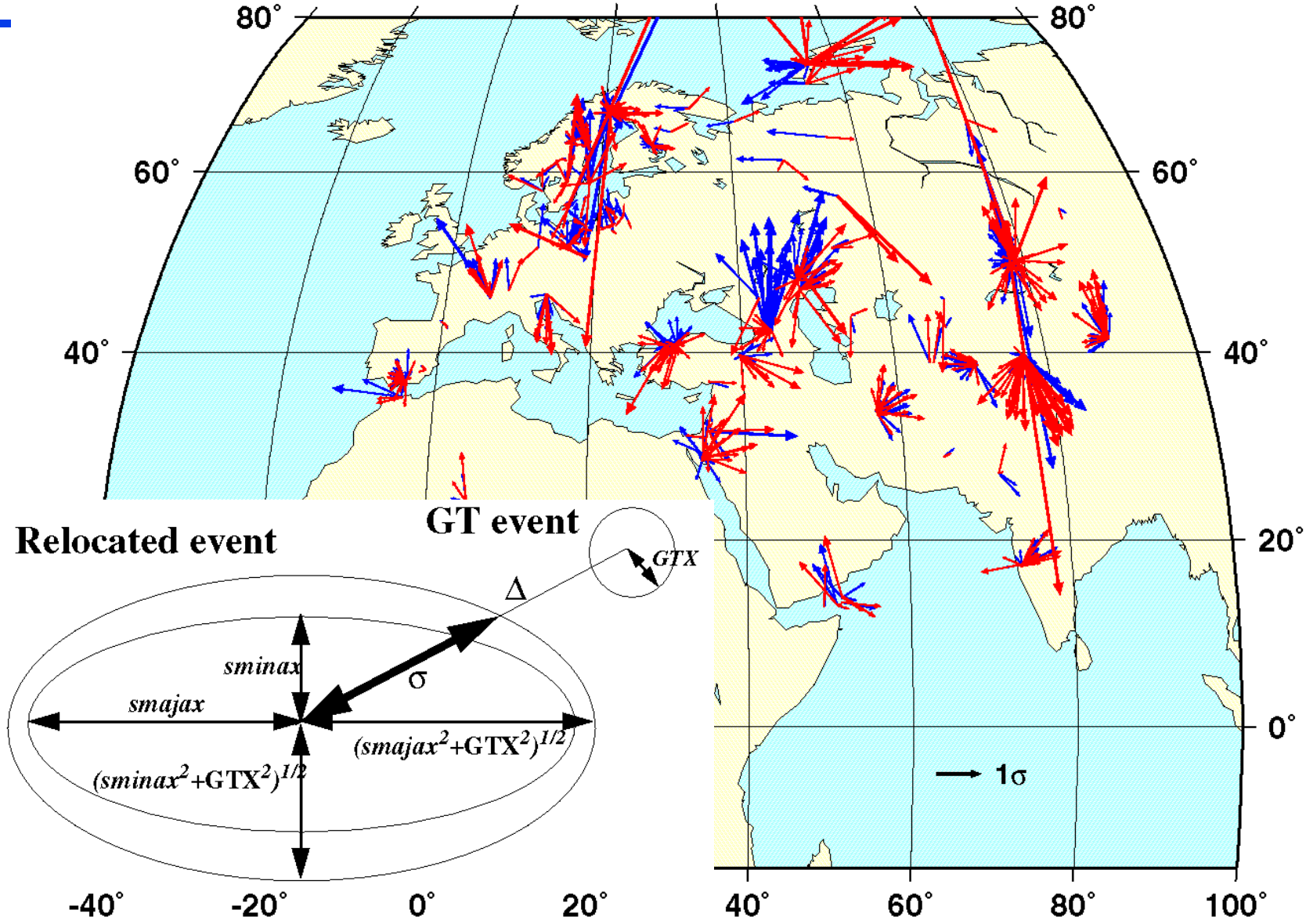
Comparison of empirical & model-based corrections

GT Event Relocation Using Pn & Sn

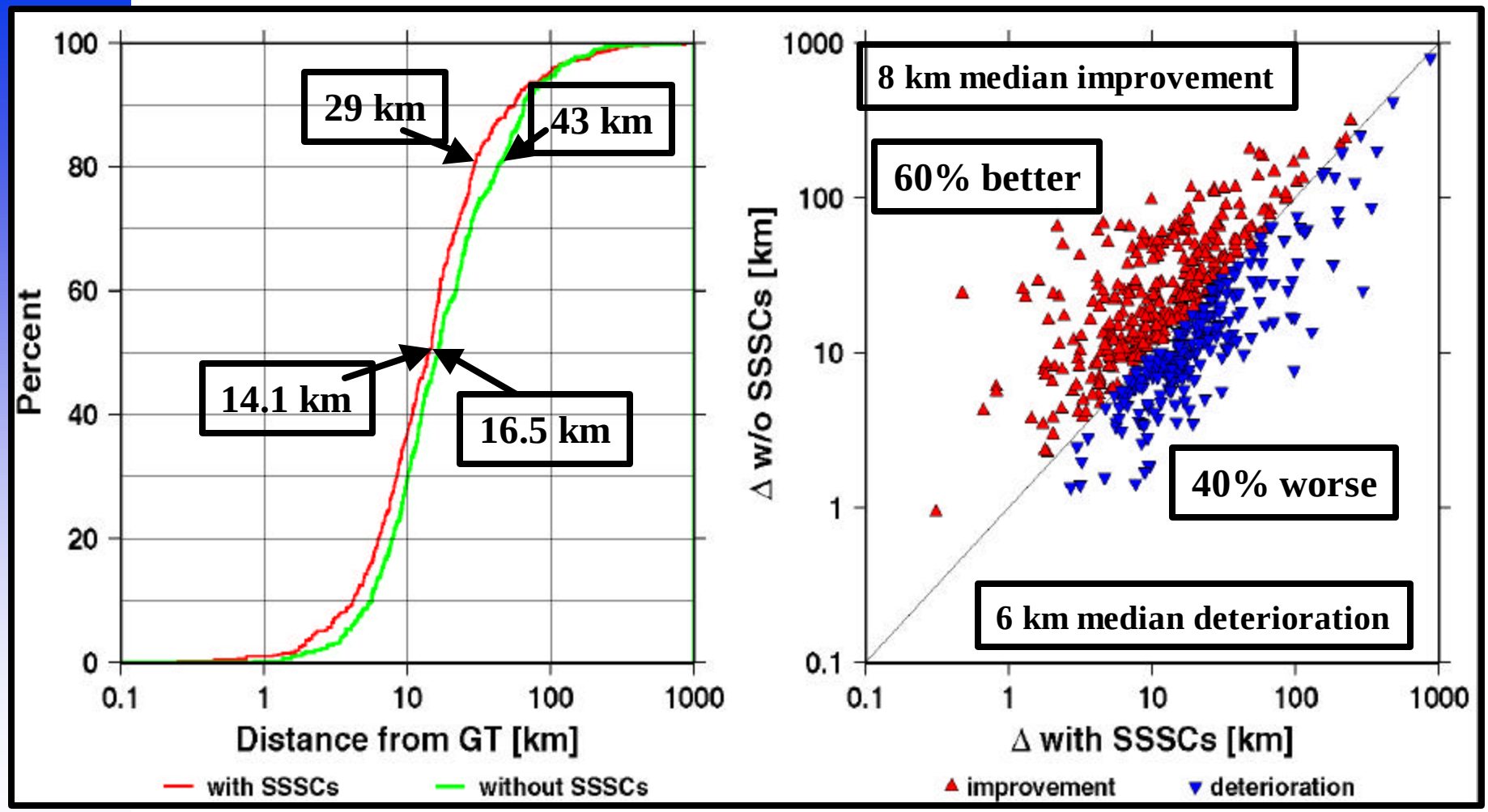
571 GT0-GT10 events relocated using Pn & Sn phases at all stations with and without SSSCs:

- **More events improved than deteriorated and improvements generally larger than deteriorations**
- **Overall mislocation improvement significant**
- **Degradation < expected by random chance most of time**
- **Error ellipse area reduced by 50% without loss of 90% coverage**
- **Origin time errors improved by 29% for almost all events**
- **Standard error of observations improved for majority of events with 17% variance reduction**
- **Met or exceeded 1999 Oslo recommendations**

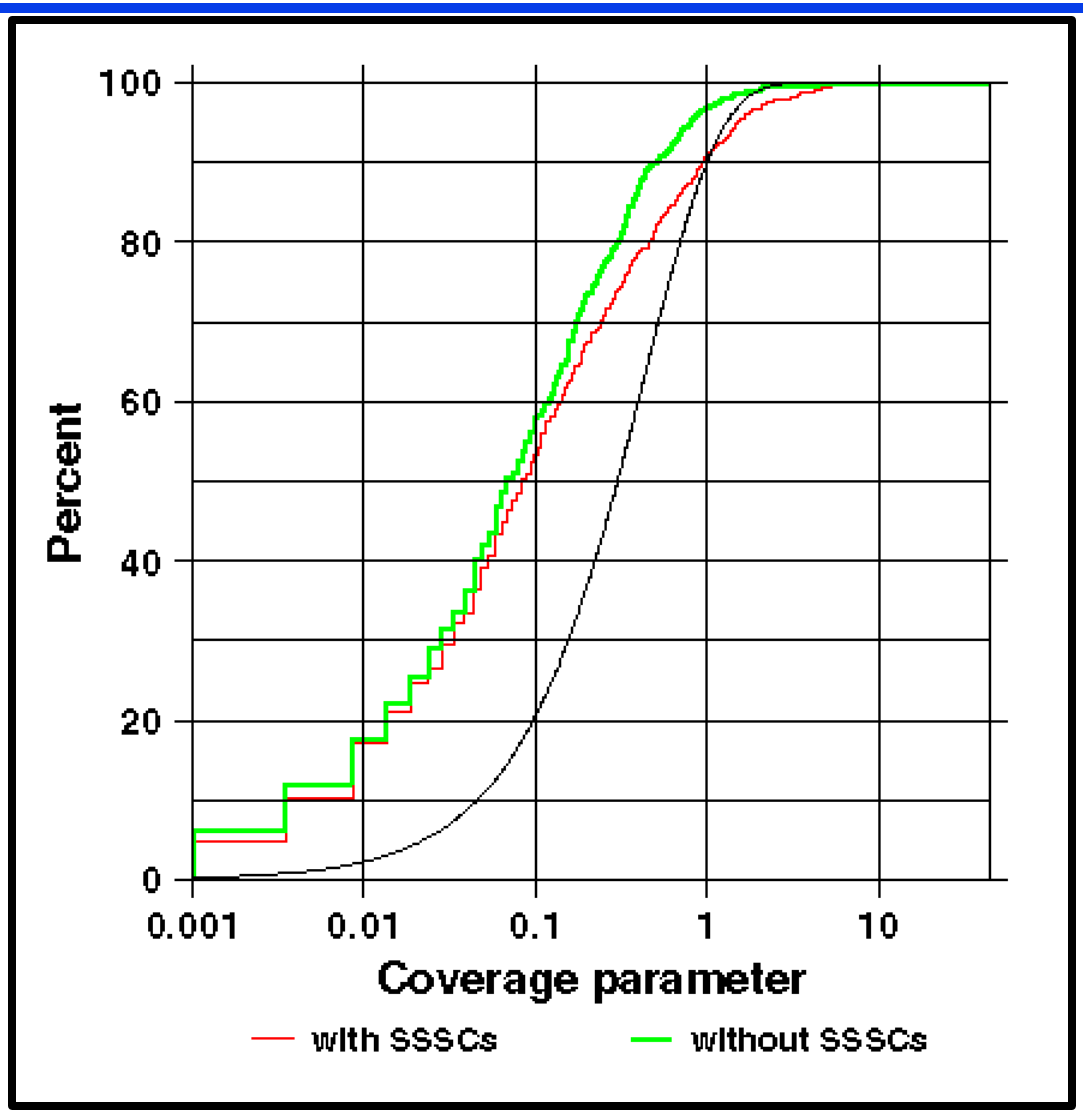
Normalized Mislocation of 571 GT0-10 Events Relocated Using Pn &Sn Only



Mislocation of 571 GT0-10 Events Using Pn & Sn Only

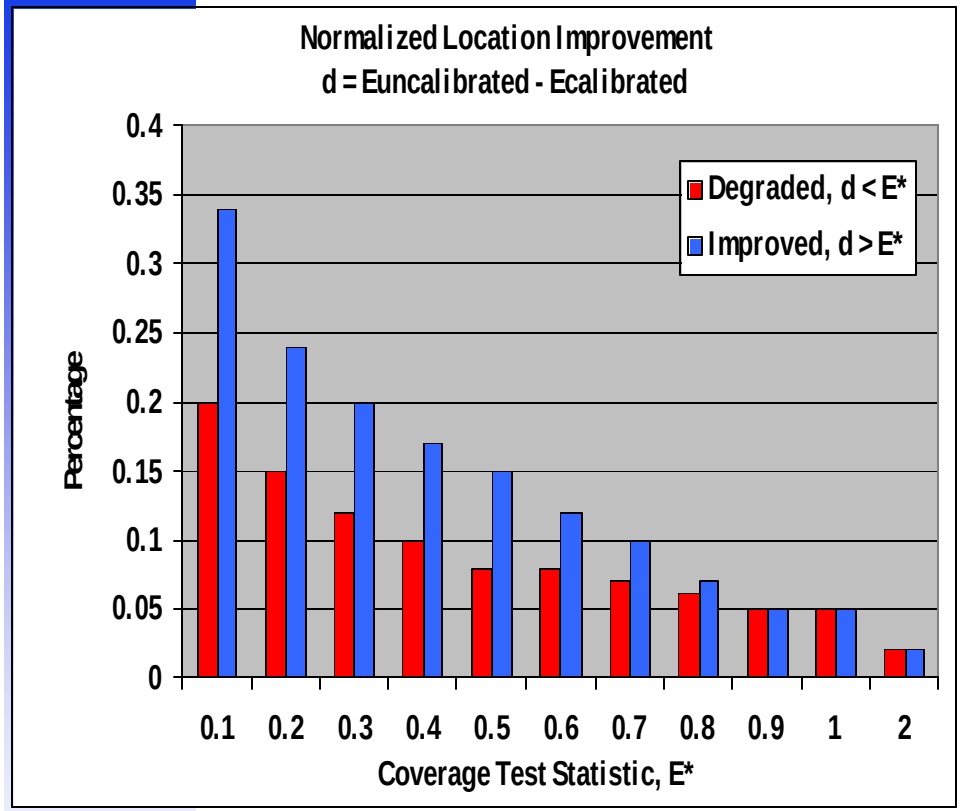


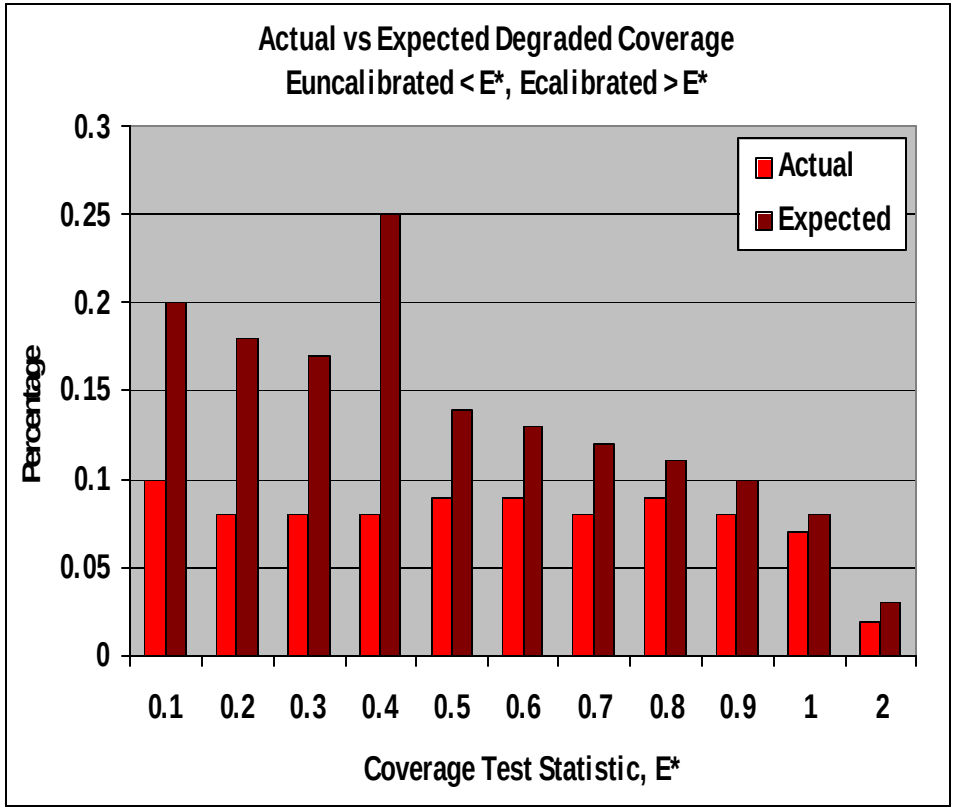
90% Coverage of 571 GT0-10 Events Using Pn & Sn Only



- Cumulative error ellipse coverage compared to c^2
- 97% coverage without SSSCs
- 91% coverage with SSSCs
- Model errors validated

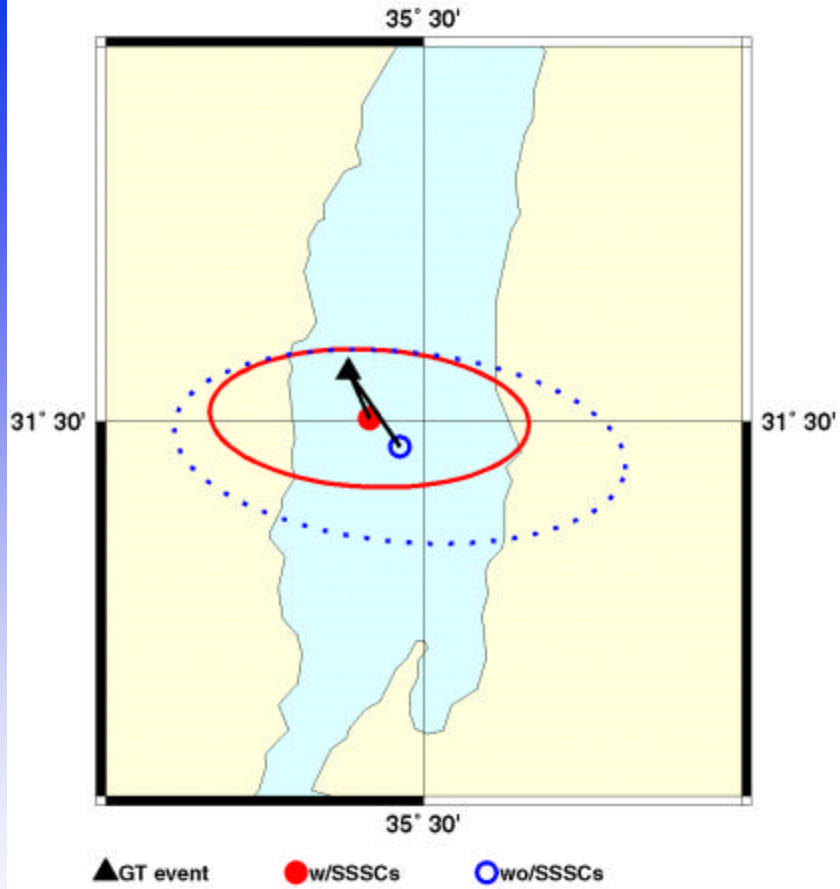
Normalized Location Improvement

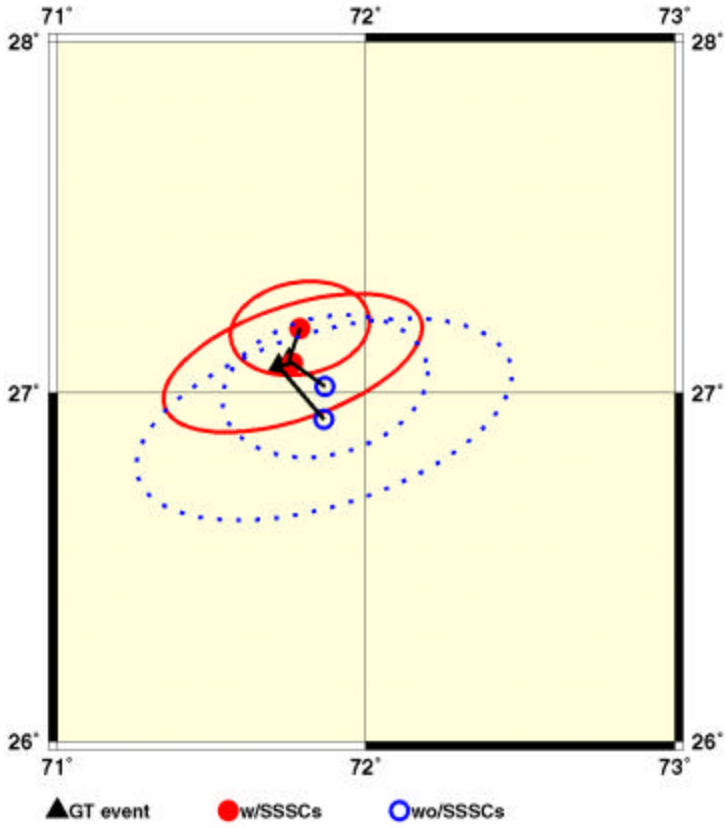




- **Improvement ^{3} degradation for all values of the test statistic**
- **Degradation is less than predicted by random chance for all values**

GT0 Event Relocation Examples Using Pn & Sn Only

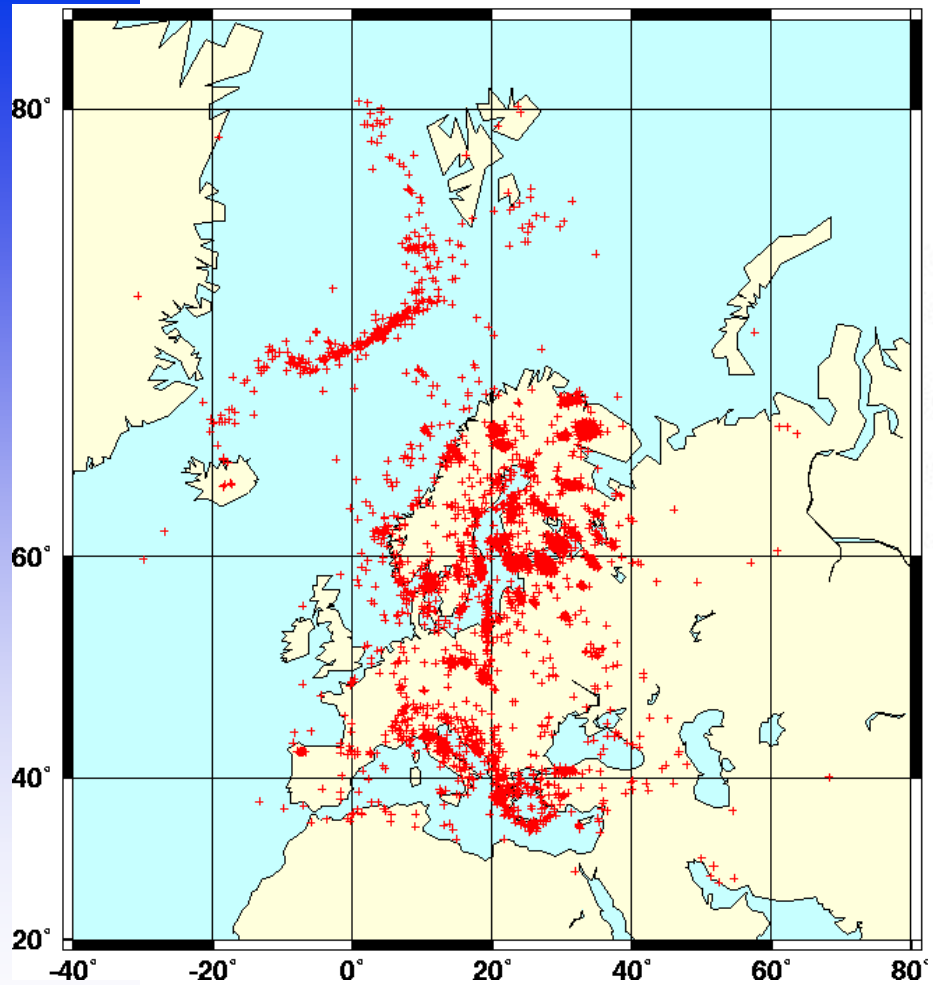


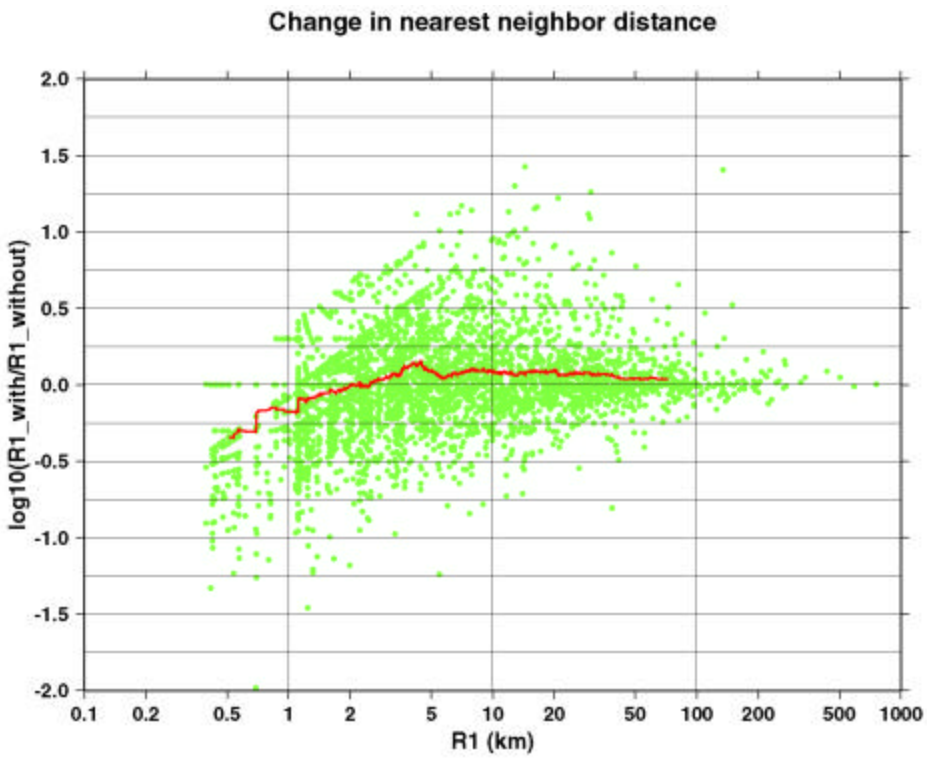


Dead Sea shot
Mislocation: 3.8 km
Improvement: 2.9 km

Indian nuclear explosions
Mislocation: 4.6, 10.8 km
Improvement: 3.4, 17.6 km

Relocation of 6835 REB Events Using Pn & Sn Only





- 12% more events converged with calibrated travel times (5685 vs 5056)

- Nearest neighbor distances decreased for pairs closer than 3 km
- Clusters became tighter

Expected Location Improvements (1)

~50% reduction of Pn & Sn model variance:

- 50% smaller error ellipses
  - Direct result of reduction in model error
  - Made possible by better travel time models
- Conservative 90% error ellipse coverage
- More usable regional phases and improved weighting between regional & teleseismic phases
  - More events converge with corrections in testing
- Validated with multiple methodologies
  - Travel time residual for large bulletin data sets
  - Multiple relocation tests of GT events & coverage
  - Correlation with empirical path corrections (cluster analysis)

Expected Location Improvements (2)

Improved Locations:

- **Significant reduction in regional location bias**
  - **Model validated by relocations using GT0-10 events**
    - **Multiple relocation tests using (Pn,Sn), (Pn, Sn, Tele), …**
    - **Multiple relocation tests using GT0, GT0-2, GT0-5, …**
    - **Statistically significant reduction in mislocation**
    - **Mislocation better than expected most of the time**
      - » **Tests account for uncertainty in GTX, measurement, and model error**
    - **Fewer deteriorated events than expected from total error model**
  - **Model validated by cluster analysis**
    - **Correlated with patterns of empirical path corrections**

Expected Location Improvements (3)

Improved Locations (cont.):

- More consistent seismicity
  - Better located Mid-ocean ridge seismicity
  - Tighter clustering of seismicity
- Reduction in Pn and Sn misfit
- Reduction in origin time error
- More events converge with regional arrivals
- More consistency between regional and teleseismic locations
- Improvements projected for sparse IMS network
  - Tests based on IMS and surrogate stations
- Consistent set of regional SSSCs and model errors for all Europe, North Africa, Middle East and Western Asia (63 stations)
  - New SSSCs consistent with previous 1D SSSCs in Fennoscandia and Northern Russia

Online Testing

- To ensure no negative impact on the system (GA & ARS) for processing large number of SSSCs
- Testing conducted on CMR R& D Testbed using:
  - 26 out of 63 IMS stations in Group-2 region with Phase 1 Pn & Sn SSSCs
  - 6 IMS stations in Fennoscandia with existing 1D Pg & Lg SSSCs
  - 22 IMS stations in North America with Pn, Sn, Pg, and Lg SSSCs
- Tests showed no significant computational impact on the system.

Conclusions

- **Preliminary IMS Pn & Sn SSSCs tested (online & offline), validated, and delivered**
- **~ 50% variance reduction in *a-priori* error model with 90% coverage**
- **SSSCs and model errors perform better than IASPEI91/IDC model errors**
- **SSSCs should improve event locations for full IMS network**
- **Median location improvement is ~10 km, so GT uncertainty must be < 5 km with high quality arrivals**
- **Phase 1 delivery integrated into IDC software**