INVESTIGATING ALTERNATIVE LOCATION METHODS AT THE ISC

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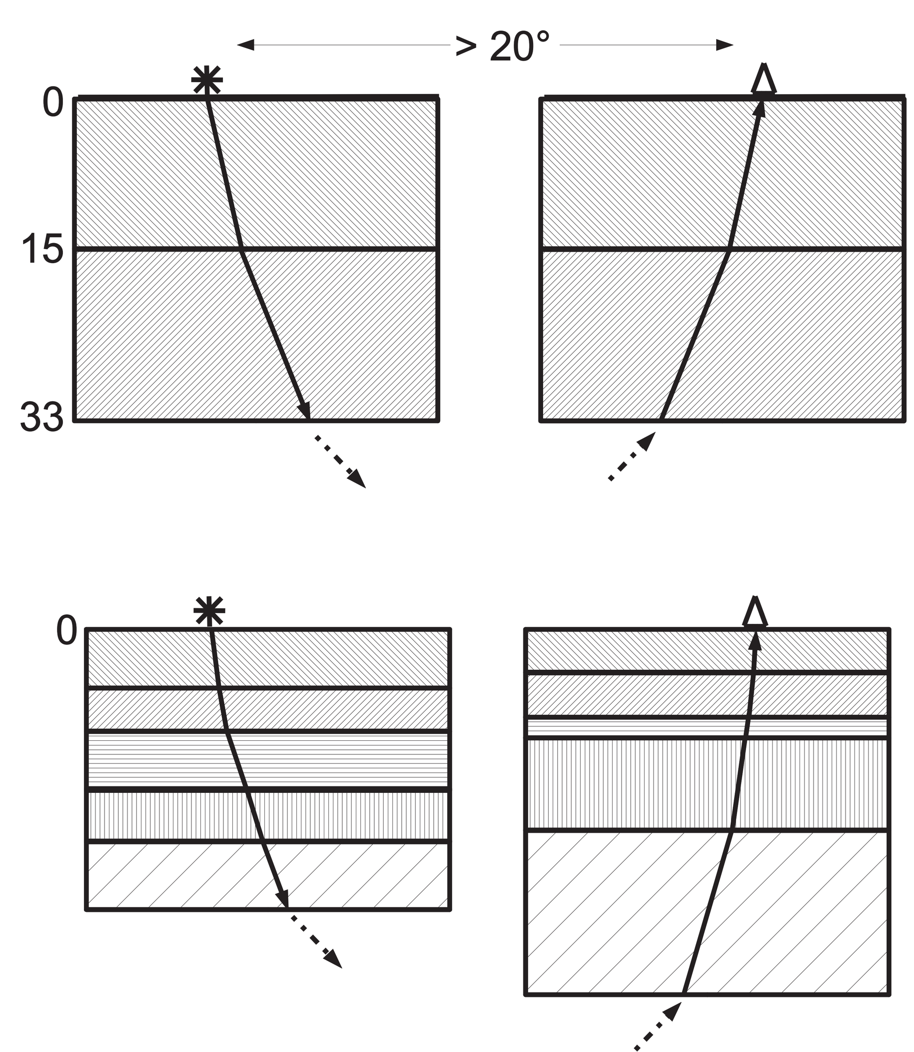
Abstract

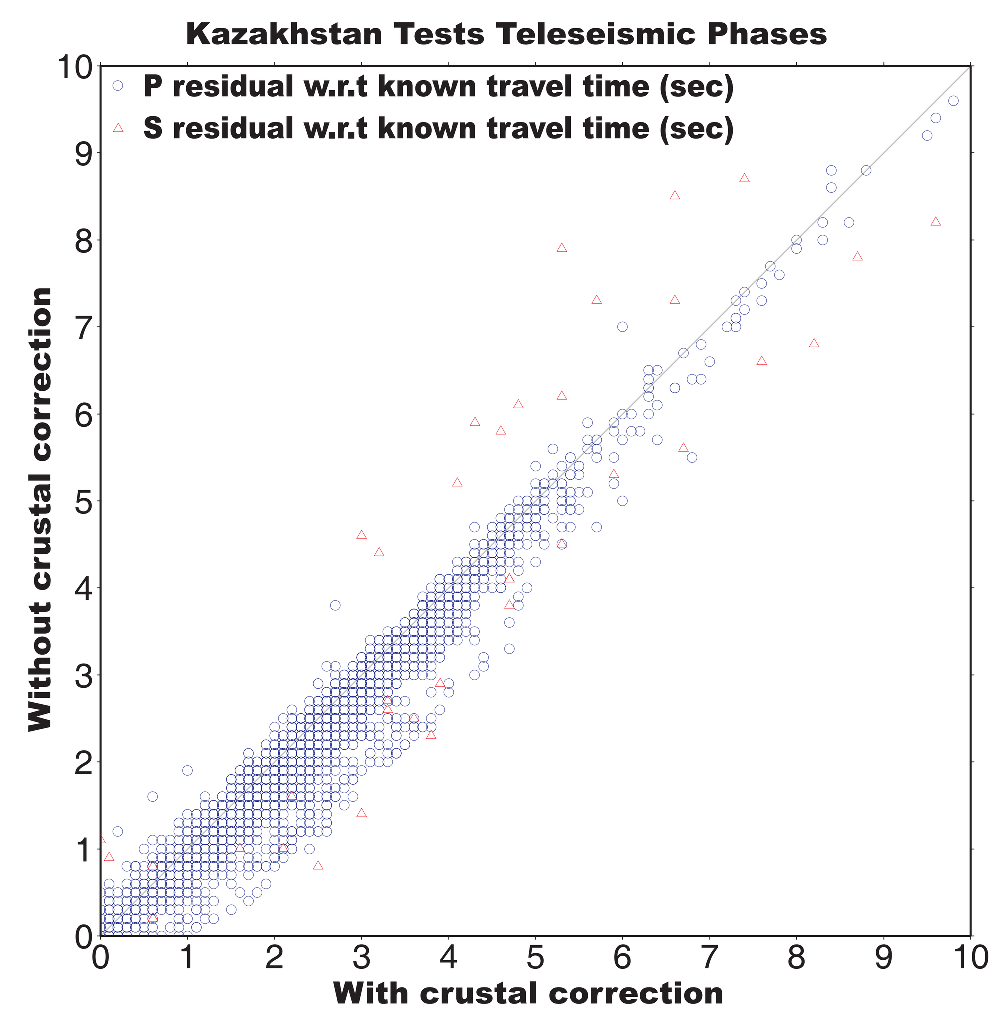
The International Seismological Centre is replacing the software it uses to calculate hypocentres, which it does using arrival times from all over the world. The new program will initially use the same algorithms as now but can also be used to test ways of improving solutions using modern methods. Here, we investigate using travel times from three dimensional earth models instead of from the Jeffreys-Bullen tables currently used. Travel times were calculated for every combination of station and source area using velocity models and ray tracing and the resulting source specific station times were stored and used in tables. Travel times for regional phases (delta less than 16 degrees) were calculated using a model for the upper mantle developed at the University of Colorado. Travel times for teleseismic phases (delta greater than 20 degrees) were calculated using a mantle model developed at Harvard University. As a test we calculated residuals for arrivals in the ISC bulletin for large nuclear explosions in Nevada and Kazakhstan. In general, the new travel time tables reduced residuals with respect to these known source times and locations and when we tried free solutions for these events the results were closer to the truth than when using existing ISC methods. Although initial indications are that solutions would improve using these methods the ISC would face many challenges if it were to adopt them for routine hypocentre computation. From a scientific perspective the models may lack sufficient resolution in regions without many earthquakes or local stations. From a technical perspective station specific tables become awkwardly large when calculated for many hundreds of stations at several depths and for various phases.

Introduction

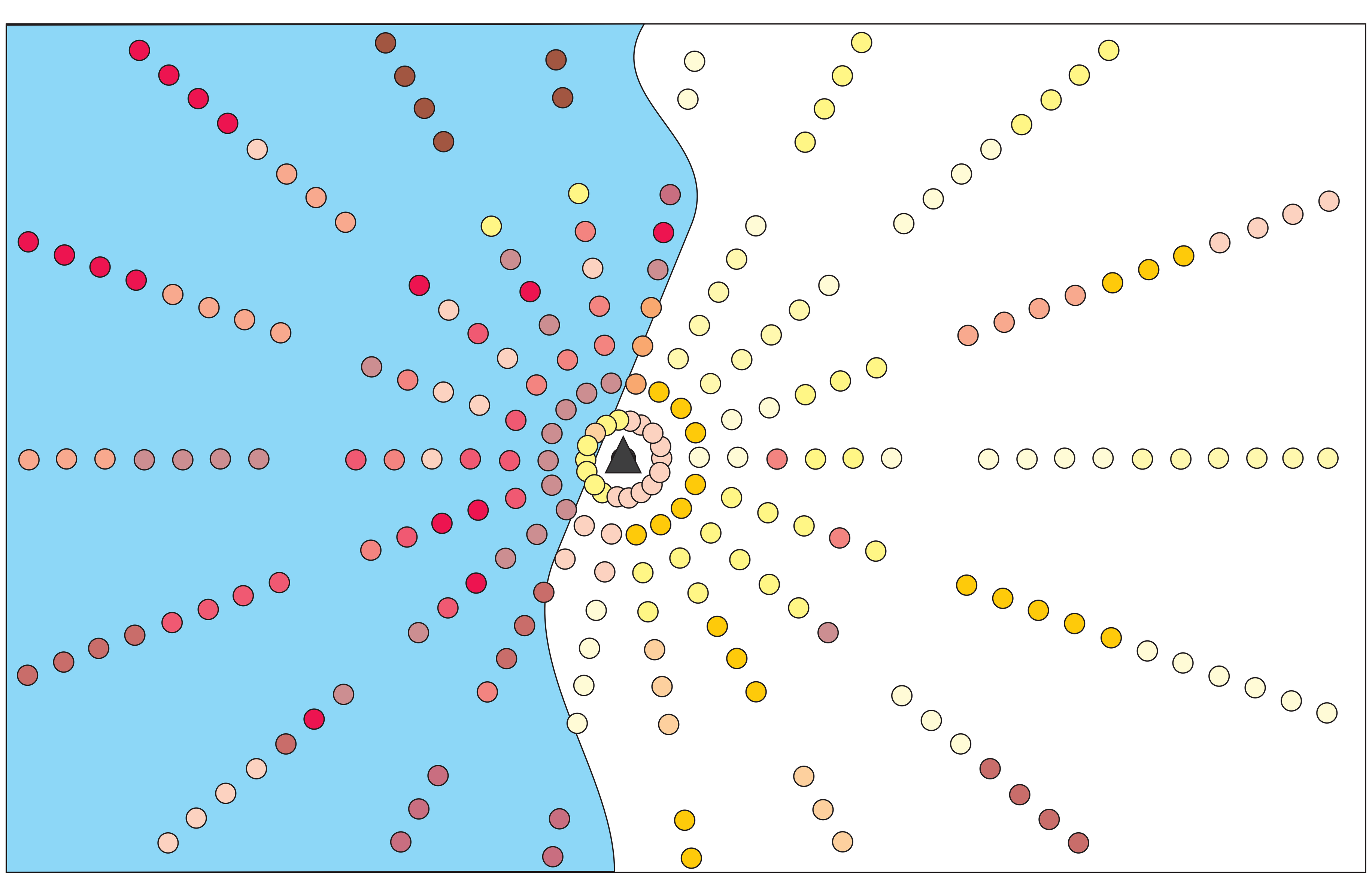
The ISC is currently reviewing the methods that are used to relocate earthquakes for the ISC bulletin. As a first step in this process we started to use S phases for the first time a year ago. This greatly improved convergence rates and the depth resolution of ISC hypocentres. Further improvements would have been extremely difficult with the existing software and a replacement location program named 'iscloc' has now been written. This program is available to download at www.isc.ac.uk/Documents/Location. Using iscloc we are experimenting into using travel times from modern earth models rather than from Jeffreys-Bullen tables as now. Separate models are being looked at for regional and teleseismic distances with a gap for source-station distances between 16 and 20 degrees where modelling ray paths is difficult. Regional travel times are found by ray tracing through a there dimensional cell model, CUB2, from the University of Colorado (Ritzwoller et al. 2002). Teleseismic travel times are found by ray tracing through a cubic spline model, J362D28, from Harvard University (Antolik et al. 2003). Both of the models incorporate the same crustal model and the first experiment that was done was to examine the effects of using this crustal model to refine Jeffreys-Bullen travel times.



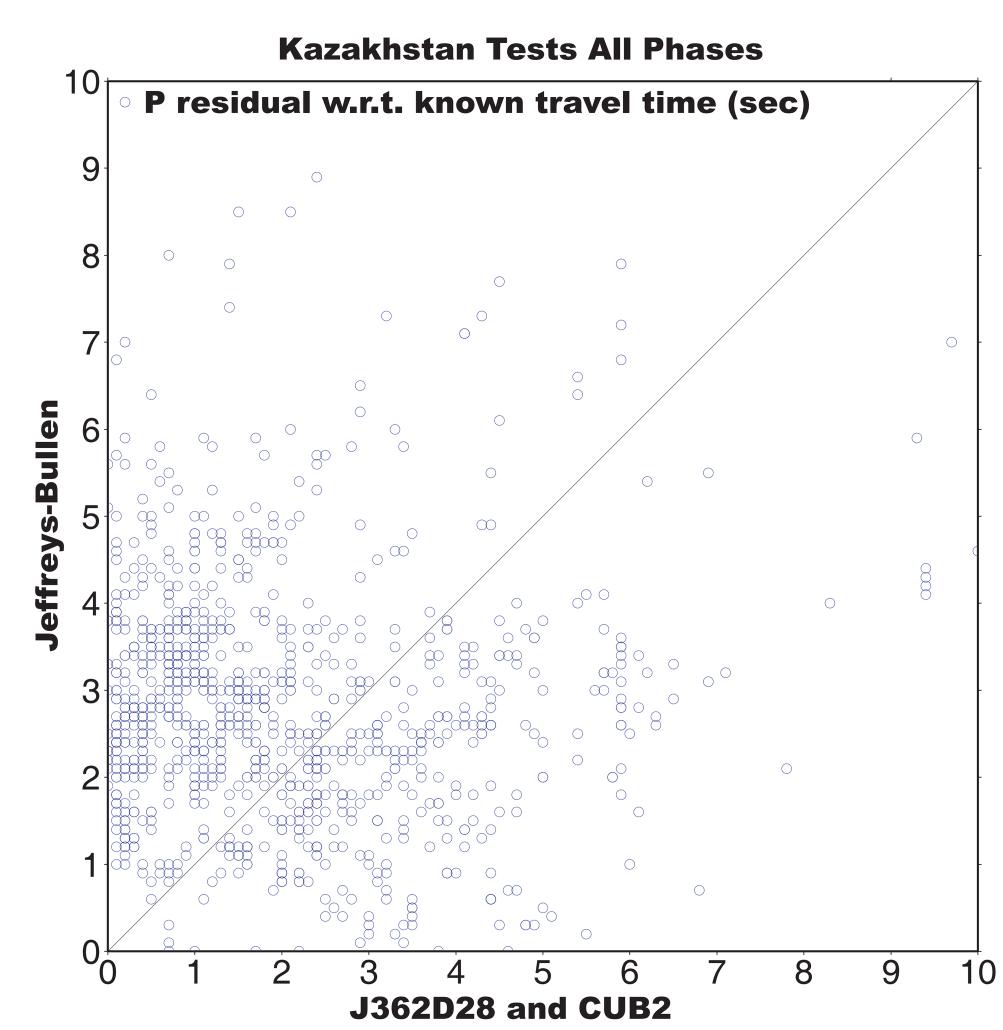
In the Jeffreys-Bullen travel time tables the crust is considered to have two layers of constant thickness and velocity all over the world. Recently a global model was made available on the Real Earth Model web site (Bassin, Laske, and Masters, 2000) that splits the crust into 2x2 degree 'tiles'. Each of these tiles has its own velocity structure based on crust type and tomography studies and 5 layers of varying thickness are used to model these structures. It is relatively simple to correct travel times for teleseismic phases (delta greater than 20 degrees) by subtracting the time that the phase would have spent in the J-B crust and replacing it with the time the phase would take to traverse the more detailed crust for the tile at the station, and for shallow sources, the tile at the source. In carrying out this correction an isostatic calculation must be made to compensate for differing thicknesses of upper mantle beneath the two crusts and for this the mantle is assumed to have the velocity of the uppermost mantle layer in the J-B earth model.



Residuals for a total of 674 stations were calculated with respect to the known location and time of 25 controlled nuclear explosions in Kazakhstan. This was done once using uncorrected Jeffreys-Bullen travel times and once correcting these travel times using the crust model as explained in the previous figure. The plot shows that many more residuals are smaller without the correction than with it. This indicates that the correction makes travel times less rather than more accurate and this was confirmed by doing similar tests for 241 controlled nuclear explosions in Nevada. There are two possible reasons that the correction does not work; either the crustal model does not accurately represent the crust beneath the stations or invalid assumptions have been made in splitting travel times from Jeffreys-Bullen tables into time spent traversing the crust and time spent elsewhere. The first explanation must sometimes be true as a 2x2 degree tile can, for example, contain high mountains as well as low coastal plains and stations in the two places would receive the same correction. Worsening residuals are, however, observed for stations in the centre of reasonably uniform tiles. The second explanation also seems likely, for example, when the Moho is shallow the uppermost mantle velocity might be slower than when the Moho is deep, rather than constant as assumed in the correction calculation. The effect of using the Laske crust as the upper part of the other two models investigated will depend on which of the two reasons put forward above is true. If the crustal model is inaccurate then it will decrease the accuracy of the new total travel times. If it is the assumption of an incorrect upper mantle velocity that is causing the residuals to increase then using the crustal model in combination with a model for the mantle could solve the problem.

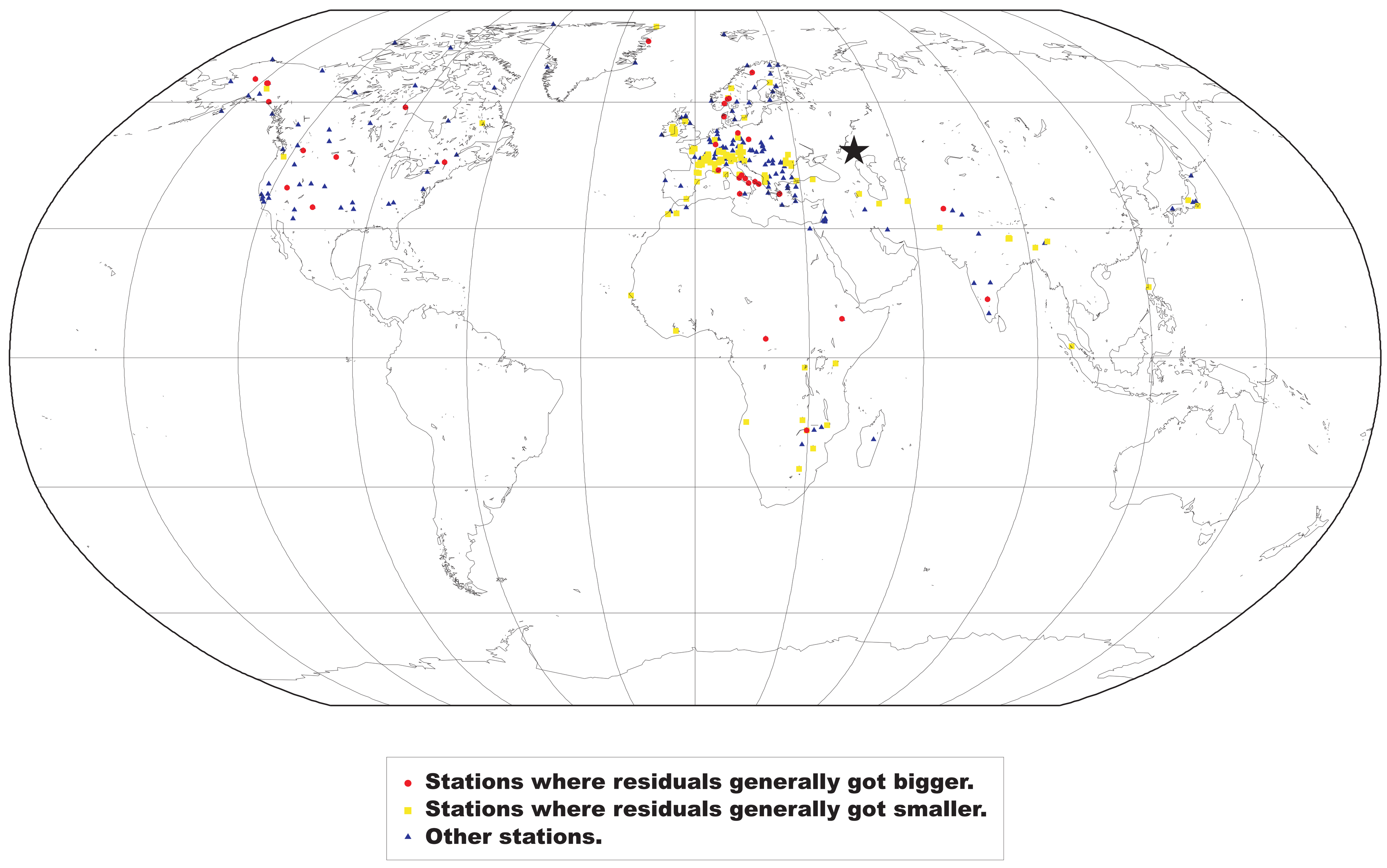


The earth models and accompanying ray tracing programs given to the ISC by Harvard University and the University of Colorado have been developed so that they output Source Specific Station Corrections (SSSCs) in the format required by the International Data Centre in Vienna for use in verifying the comprehensive test ban treaty. This takes the form of a table of corrections for each station with values given at intervals of latitude and longitude. These corrections are added to the IASPEI travel time for a phase originating at a near surface source with such a latitude and longitude and recorded by the station in question. The ISC proposes to use the same models and ray tracers to produce tables that are more immediately useful to our new location program. These will take the form of a set of tables of travel times for each station with values given at intervals of distance and source depth. One table will be required for each interval in back azimuth between the station and source. Figure 3 explains this by plotting surface source travel times for an imaginary coastal station _ faster travel times are red and slower ones in yellow. Note the gap in travel times between 16 and 20 degrees away from the station where there is no coverage from either model.



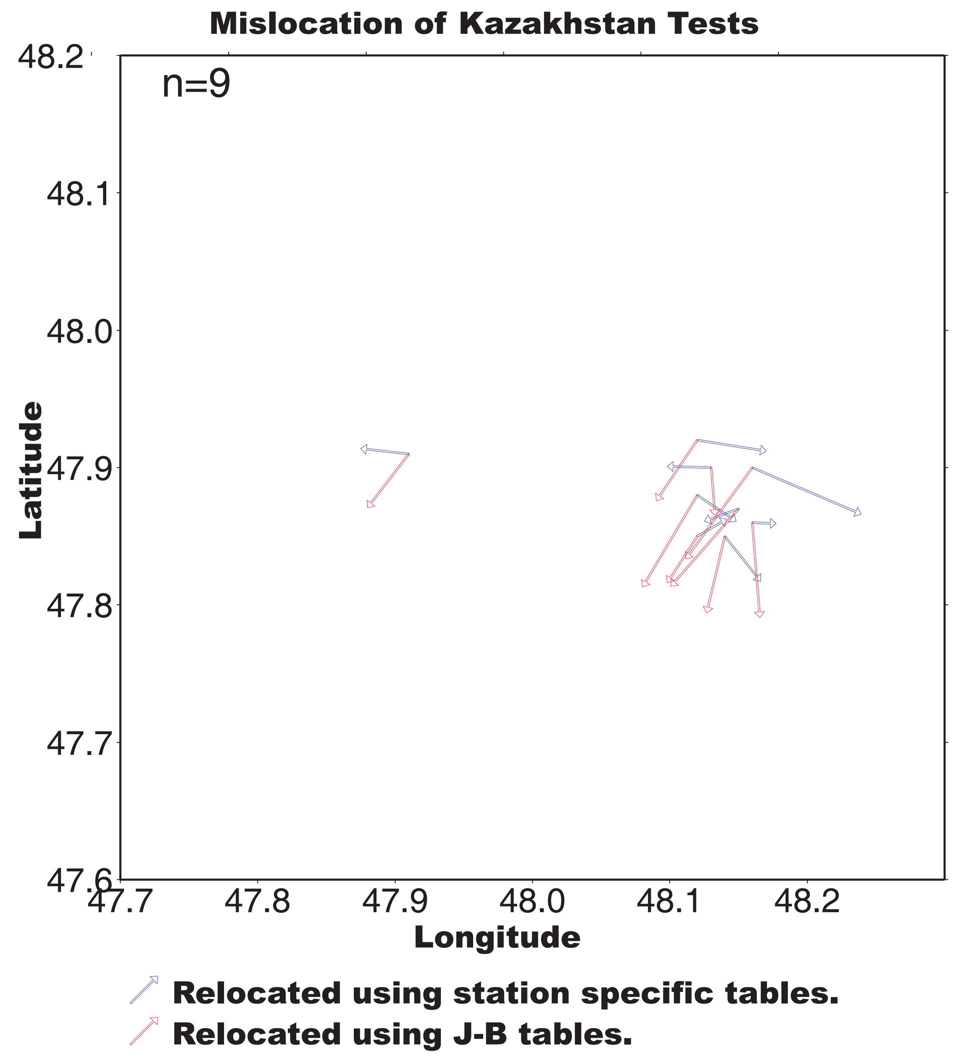
Travel times from the two earth models together are tested in a similar manner to that shown previously for the crustal correction. Times are calculated for ground truth events in Kazakhstan by interpolating between table values that were obtained by ray tracing. These are then subtracted from the actual travel times and the residuals are compared to those for Jeffreys-Bullen travel times. As can be seen, the times from the tables produced from the models are closer to reality more often than those from J-B. This only tests one source area but does test many different stations and both models (the models individually also generally reduce residuals for those stations within the corresponding range of distances from the source).

Residuals for Kazakhstan Tests.



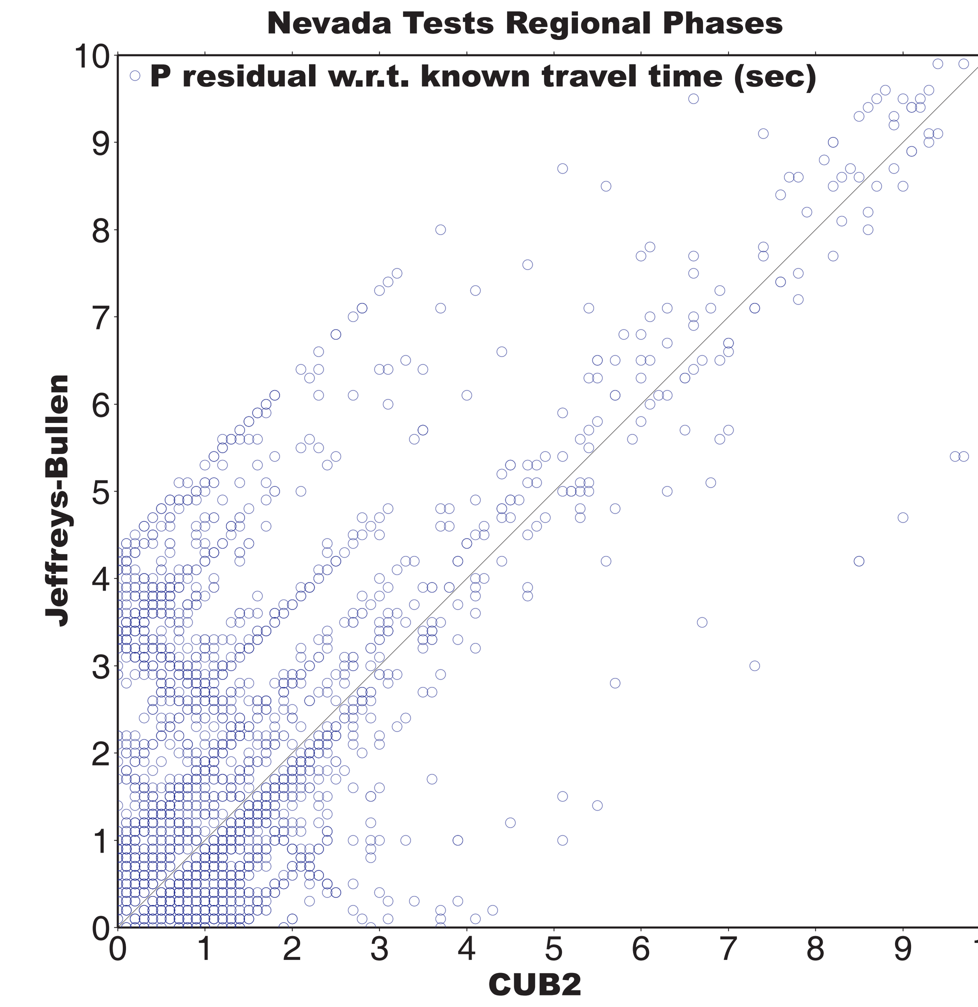
The residuals for the new travel time tables are better than Jeffreys-Bullen residuals for most stations reporting the Kazakhstan tests. There are however cases where the opposite is true and it would be interesting if there was a pattern as to which stations improved and which didn't. This map shows stations that contributed P phases to at least 3 of the test events and they are coloured to indicate whether the residuals for these phases are generally better or worse than they are using J-B. The green stations are those where residuals are better for more than 74% of events. The red stations are those where residuals are worse for more than 74% of events. Other stations are plotted in blue. No obvious geographical pattern can be seen in the distribution of stations although it is clear how few local stations there are in the ISC database that contribute to several of these tests. These tests are a better for testing the Harvard model we are using for distances greater than 20 degrees and do not contribute much data for consideration of the CUB2 model used for regional phases.

Mislocation of Kazakhstan Tests



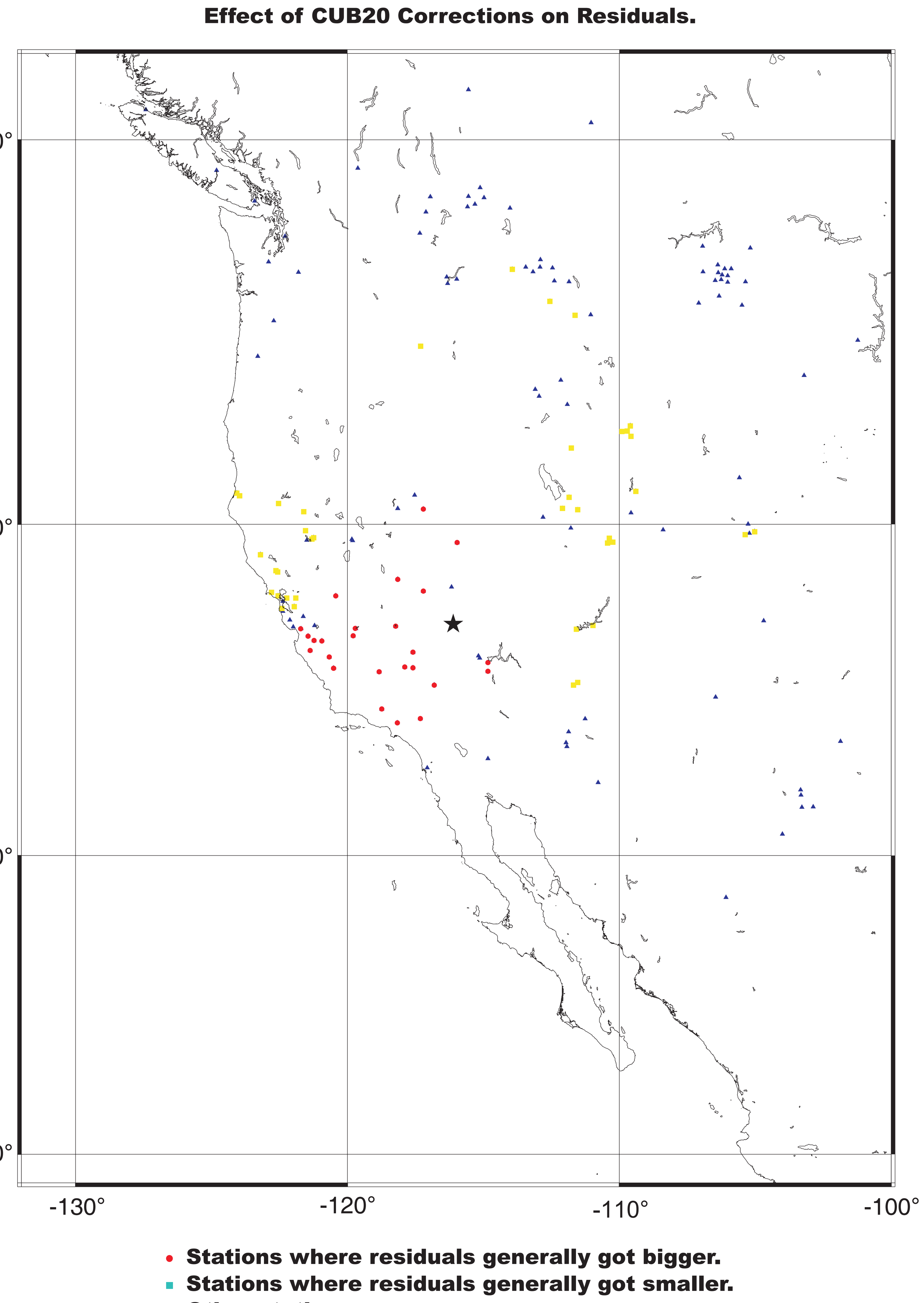
The majority of residuals with respect to known travel times for ground truth locations are smaller using the new travel time tables than when using Jeffreys-Bullen tables, as the ISC does now. One would thus expect more accurate results when free locations are carried out using the new tables. This is confirmed here where the two solutions are plotted as mislocation vectors in relation to the actual origins of one group of the Kazakhstan tests. The vectors for the new locations are shorter in every case than those for the current ISC solutions.

Nevada Tests Regional Phases



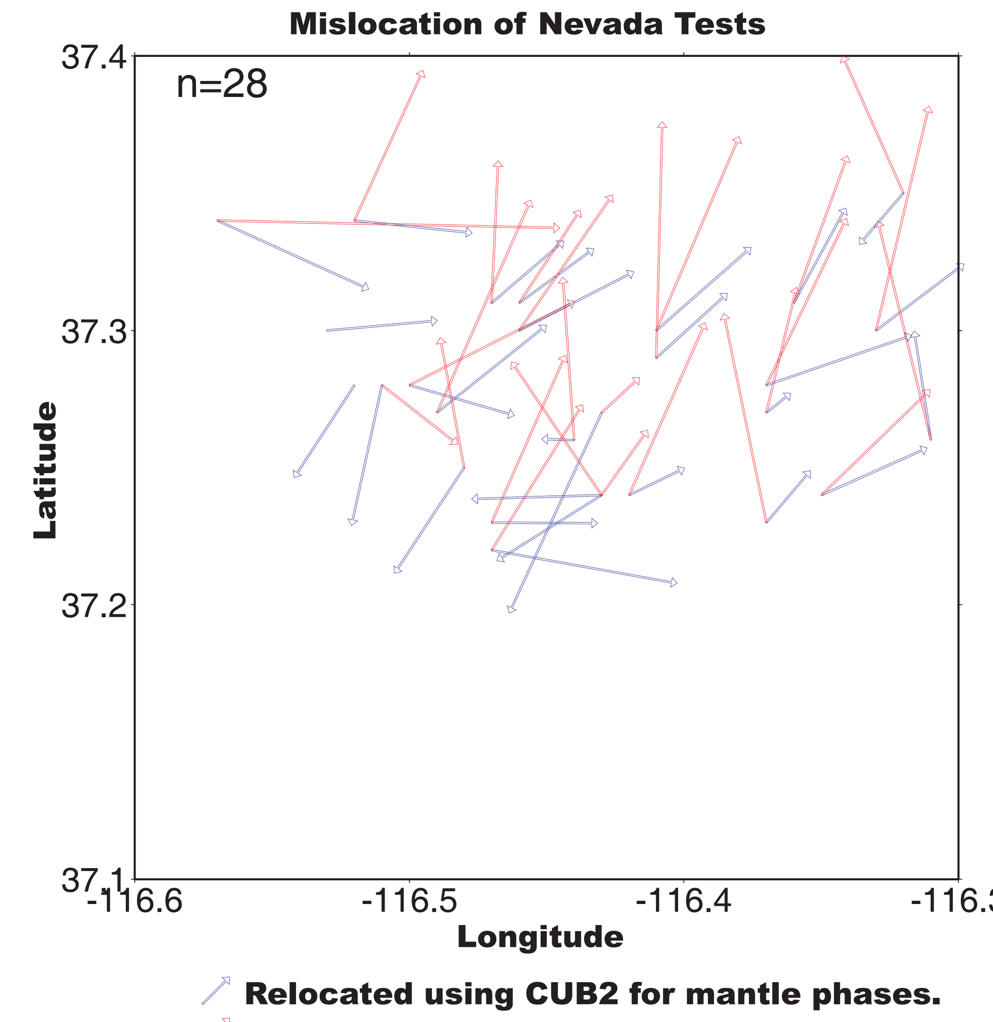
More than one source region needs to be considered when testing source specific travel time tables and the second set of ground truth events considered here is the nuclear tests in Nevada. So far the ISC has not calculated the travel times required to create tables for all of the stations that recorded teleseismic phases from these tests. Instead only regional stations are examined and so only the CUB2 model is being tested. It can be seen that residuals for the new travel time tables are smaller more often than the Jeffreys-Bullen residuals.

Effect of CUB20 Corrections on Residuals.



This map shows stations that contributed regional P phases to at least 3 of the Nevada test events. The green stations are those where residuals are better for the new travel time tables for more than 74% of events. The red stations are those where residuals are better for Jeffreys-Bullen tables for more than 74% of events. Other stations are plotted in blue. The stations very close to the events are missing because travel time correction tables have not been calculated for Pg. Doing so would be a challenge because of the abrupt discontinuities in the crustal model. This may also be the reason that most of the nearest stations investigated have residuals that are worse using CUB2 than using Jeffreys-Bullen, Pn waves travelling along the Moho will have been modelled over some sharp steps in Moho depth to calculate these travel times. One way to remedy this problem may be to replace the crustal part of CUB2 with a simple two layer crust for small delta and we are experimenting along these lines at the moment.

Mislocation of Nevada Tests



Despite the problems with nearby stations, residuals from the CUB2 tables are generally smaller than those from Jeffreys-Bullen and so one would expect locations to be more accurate using the new tables. This is shown to be true here for one group of the Nevada test events. The two blue vectors on their own indicate events where a solution was not achieved using J-B travel times but where a convergence was reached using the new travel time tables.

Conclusion

The use of travel time tables calculated for each station using detailed earth models has been shown to improve relocations of ground truth events in Kazakhstan and Nevada. This indicates a possible avenue for the ISC to pursue to make their reloctaions more accurate. However, it would be necessary to calculate and store a set of travel time tables for over 2000 stations for at least P, S and crustal phases. Even at a reasonably coarse spacing in azimuth and delta and at a limited selection of depths this would require over 3000 Mbytes of data. Currently, travel time tables are held in memory by the relocation program but this strategy would have to be reassessed for such large amounts of data. One solution would be to populate the tables sparsely with only those areas of the globe where events have actually been recorded by a given station having travel times included.

If the ISC decide to adopt these type of travel time tables then much more testing is necessary before they can be included in normal procedures, both to prove that a significant improvement in earthquake location is achieved in comparison with the use of existing travel time tables and to fine tune the way that the new methods are applied. Potential problems such as inaccuracies at small delta will have to be addressed. A workshop is planned at the IASPEI general assembly in autumn 2005 to discuss recent developments in earthquake location. This will be an ideal forum to discuss which global models are at that time best for ISC purposes, as well as to consider solutions to possible problems.

Investigating Alternative Location Methods at the ISC

Eos Trans. AGU, 84, Fall Meet. Suppl., Abstract S21D-0334
A poster in Tuesday morning session S21D, Earthquake Location: Applications and Developments of New Techniques 1 Posters

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Poster in PDF format part 1 and part 2