IDENTIFICATION AND VALIDATION OF REFERENCE EVENTS WITHIN THE AREA BEING REGIONALLY MONITORED BY IMS STATIONS IN ASIA AND NORTH AFRICA

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ABSTRACT

High-resolution cluster analysis is applied to explosions and earthquake sequences in Asia and North Africa for which one or more of the associated events is known to an accuracy of 5 km or better (GT5). In particular, we analyze phase data reported to the ISC and NEIC for the 1997 Ghaen-Birjand earthquake sequence in eastern Iran and the 1997 Jiashi swarm in western China. In both cases, reference event data is available from short-term portable seismograph deployments following the initiation of seismic activity in those regions. For the cluster analyses we used 92 events of the Iran sequence and 123 events of the Jiashi swarm, ranging in magnitude from 3.4 to 7.1. The analyses produce new locations (relative to the centroid) and 90% confidence ellipses that sharpen the spatial relationship of the earthquakes to known faults and modes of deformation in these regions. Shifting the centroid to match reference event locations produces source-station path corrections (to ak135) for regional seismic phases recorded by IMS and surrogate stations in Asia. The standard error of these path corrections is typically only a few tenths of seconds. Hence, these data can be used to validate 3-D models and to support the calculation of travel-time curves and source-specific station corrections for the Asian and north African regions.

Key Words: Reference Events, Cluster Analysis, Path Corrections

OBJECTIVE

The primary objective of this research effort is to develop a comprehensive reference event database with validated travel-time information for regional seismic phases recorded by IMS and surrogate stations in Asia and North Africa. This database can be used to support the calculation of regional travel-time curves and source-specific station corrections.

RESEARCH ACCOMPLISHED

Method

Validation of potential reference events is performed in two steps. First, ISC/NEIC reported phase arrival times from event clusters are used to perform some simple tests of location uncertainties using the EHB location algorithm (Engdahl et al., 1998). Second, further analysis of the events is performed by multiple event relocation (cluster) analysis using the method of Hypocentroidal Decomposition (HDC; Jordan and Sverdrup, 1981) HDC is used because it makes maximal use of all available data and it carries the a priori error budget through the analysis in a completely rigorous manner. Results of the cluster analysis may reveal the effects of small-scale lateral heterogeneities (on the order of tens of kilometers), perhaps requiring (data permitting) further sub-division of the original cluster into sub-clusters for separate analyses. A final product of this validation process for an event cluster (or sub-clusters) is a set of source-station path corrections for each phase reported, with statistics. These corrections can then be used in developing calibration correction surfaces for individual IMS and surrogate stations.

Application

In this report, we analyze phase data reported to the ISC and NEIC for the 1997 Ghaen-Birjand earthquake sequence in eastern Iran and the 1997 Jiashi swarm in western China. Nearly all the events in this study have magnitudes of 3.5 or greater. In both cases, reference event data is available from short-term portable seismograph deployments following the initiation of seismic activity. For the cluster analyses we used 92 events of the Iran sequence and 123 events of the Jiashi swarm, ranging in magnitude from 3.4 to 7.1. The analyses produce new locations which are defined by "cluster vectors" in space and origin time, relative to the centroid which is then located in the traditional manner to yield absolute locations and origin times. If one or more reference events are included in the cluster, the centroid can be shifted to provide the optimal match to the reference locations, which brings all events in the cluster into close alignment with "ground truth". The expanded set of corrected hypocenters is then available to calculate source-station path corrections relative to the Earth model ak135 (Kennett et al., 1995) for regional seismic phases recorded by IMS and surrogate stations in Asia.

Iran Sequence

On May 10, 1997, a damaging multiple event (called the Ghaen-Birjand earthquake) occurred in a region of high seismicity at the boundary of the Lut Block in eastern Iran. The Geophysics Institute at Tehran University reported that the quake was accompanied by a surface rupture which included three segments with a total length of 113 km or (by excluding inter-segment distances) a length of 87 km. The spatial and temporal distribution of aftershocks revealed two barriers along the fault line at inter-segment distances. Five months later the second period of aftershock activity began along the southern end of the surface rupture while the northern part was quiescent.

Phase data was reported to ISC and NEIC for 92 events near the fault traces of this earthquake through 1999, but only three of these events were larger than mb 4.9. Nevertheless, we were able to successfully perform a cluster analysis of the data set. Plotted in Figure 1 are the HDC locations of 42 events in the sequence that have 90% confidence ellipses with areas equivalent to that of a circle with radius 10 km. The correlation of our HDC locations to mapped faults in the region, perhaps with only a slight northerly bias, is remarkable. We are collaborating with the researchers in Tehran who carried out the field study of this sequence to obtain more information about any of the events in the HDC analysis which were well-recorded by the temporary deployment of portable seismographs following the main shock, in order to establish as many reference locations for this cluster as possible. Nevertheless, it is instructive to estimate Pn source-station path corrections from residuals computed with respect to our HDC locations. Because of outlier residuals, we use a robust median statistics approach to estimate the median, spread and standard error of Pn residuals at each reporting station using an algorithm programmed by R. Buland (personal communication). In Figure 2 are plotted the more reliable of these medians for 16 stations at distances up to 20 degrees from the source region of the sequence. The range of these Pn corrections which are based entirely on HDC locations is about +/- 4sec and they seem to be spatially correlated.

Jiashi Swarm

In 1997 a strong earthquake swarm occurred in an intraplate region of western China (Jiashi county) at the edge of the Tarim basin. In the 10 months following the onset of this activity phase data were reported to ISC and NEIC for 123 events within a small area (50 x 50 km) of the region. Of these 123 events, 113 were mb 3.5 or larger, with 8 larger than mb 4.9. A temporary deployment of 3 portable seismographs within distances of less than 30 km from events in the swarm captured an mb 4.7event in the swarm. Data from these stations and other permanent stations at distances less than 250 km from the source were used by Chinese scientists to locate this event using a local crustal model. Hence, it qualifies as a reference event. A cluster analysis of the swarm produced HDC locations for 57 events that have 90% confidence ellipses with areas equivalent to that of a circle with radius 5 km. These HDC locations were shifted by moving the centroid of the cluster so that the HDC location of the reference event matched the ground truth location. The resulting high resolution locations are plotted in Figure 3. The pattern of epicenters is confined to a small region but does not appear to display any lineation that would indicate that the events belong to a single fault. Focal mechanisms of the larger swarm events indicate both strike slip and normal faulting, which, in combination with the pattern of epicenters, is consistent with a complex, diffuse pattern of deformation.

As we did for the Iran sequence, we estimate the median, spread and standard error of Pn residuals at each reporting station and plot the more reliable median estimates for 57 stations at distances up to 20 degrees from the source region of the swarm. However, in the case of the Jiashi swarm, we use residuals based on HDC locations which have been shifted to match the reference event. The shift required is 10.4 km at an azimuth of 18° and a surprisingly large change in origin time, 2.8 seconds earlier. The medians plotted in Figure 4 are quite large, ranging from +8 to -3 sec, suggesting a possible error in the origin time of the reference event. To better understand the problem we plot in Figure 5a medians based on residuals for unshifted HDC locations and in Figure 5b medians based on reference event locations for Lop Nor explosions (nearly 900 km from the Jiashi source region) estimated using cluster analysis (JED) by Terry Wallace (personal communication). The comparison is not conclusive but the possibility of a problem in the origin time estimate for the Jiashi swarm reference event seems likely. Additional information, such as the arrival times and crustal model used to locate the reference event will be needed before these corrections can be validated. We are attempting to confirm the reliability of the reference location with the researchers who conducted the aftershock study.

CONCLUSIONS AND RECOMMENDATIONS

High-resolution cluster analysis is being applied to earthquake sequences in Asia and North Africa for which one or more of the associated events is known to an accuracy of 5 km or better (GT5). In particular, we analyze phase data reported to the ISC and NEIC for the 1997 Ghaen-Birjand earthquake sequence in eastern Iran and the 1997 Jiashi swarm in western China. In both cases, reference event data is available from short-term portable seismograph deployments following the initiation of seismic activity in those regions. For the cluster analyses we used 92 events of the Iran sequence and 123 events of the Jiashi swarm, ranging in magnitude from 3.4 to 7.1. The analyses produce new locations (relative to the centroid) and 90% confidence ellipses that in the case of the Iran sequence sharpen the spatial relationship of the earthquakes to known faults in that regions. Shifting the centroid to match a reference event location for the Jiashi swarm event produces source-station path corrections relative to ak135 of regional Pn phases recorded by stations in Asia. The standard deviation of these path corrections is typically only a few tenths of seconds. Hence, these data can eventually be used to validate 3-D models and to support the calculation of travel-time curves and source-specific station corrections for the Asian region.

Our initial work with the candidate "reference events" in the two regions suggests that considerable care must be taken to ensure reliable results. Many aftershock studies and temporary seismograph deployments in remote areas suffer from logistical, operational, and analytical difficulties which may compromise the quality of the computed locations. Such problems are seldom apparent in published papers and abstracts. In many cases it will be necessary to gain access to raw data and analysis records—and most importantly, to gain the cooperation of the original researchers— to confirm the reliability of "reference events" offered by the seismological community in these regions.

REFERENCES

Engdahl, E. R., R.D. Van der Hilst and R.P. Buland, Global teleseismic earthquake relocation with improved travel times and procedures for depth determination, Bull. Seism. Soc. Amer., 88, 722-743, 1998.

Jordan, T.H. and K.A. Sverdrup,. Teleseismic location techniques and their application to earthquake clusters in the south-central Pacific, Bull. Seis. Soc. Amer., 71, 1105-1130, 1981.

Kennett, B. L. N., E.R. Engdahl and R.P. Buland, Constraints on seismic velocities in the Earth from traveltimes, Geophys. J. Int., 122, 108-124, 1995.

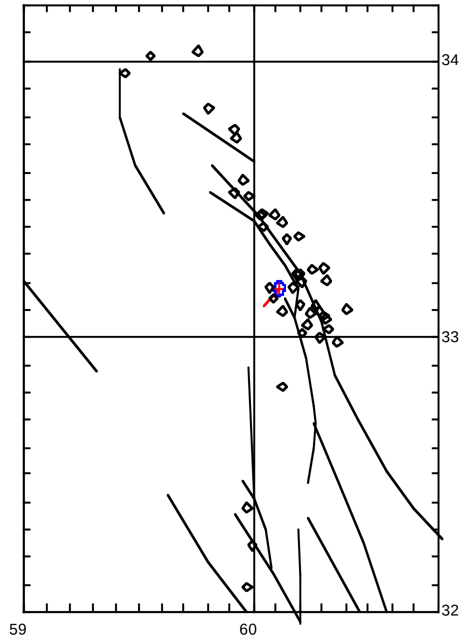

Figure 1. Map of the Ghaen-Birjand region in eastern Iran showing major mapped fault traces. Epicenters of 42 of the best-located events (area of 90% confidence ellipse less than 314 km^2, equivalent to a circle with 10 km radius) based on HDC analysis of the 1997 earthquake sequence are shown. Tics are 0.1 deg.

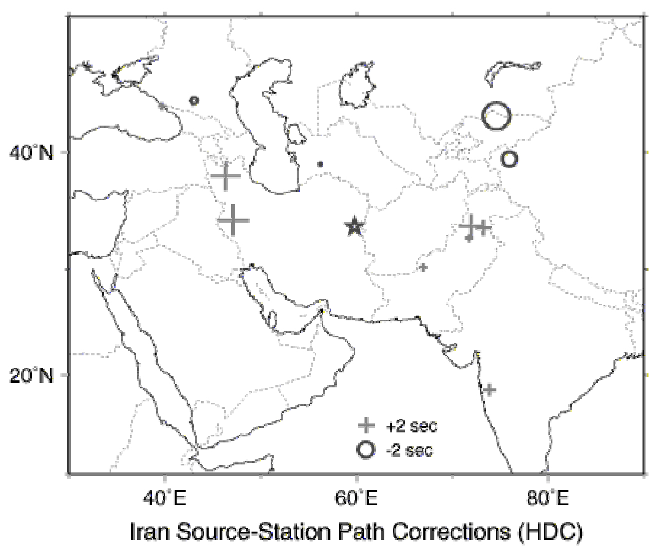

Figure 2. Source-station Pn path corrections based on median residuals to stations using HDC locations. Only stations which observed at least 5 Pn arrivals and with standard errors of less than 0.5 sec are plotted. Star is location of Ghaen-Birjand mainshock.

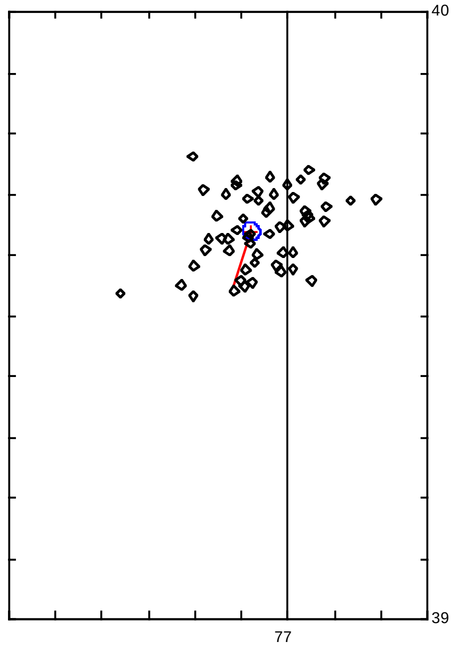

Figure 3. Locations of the 57 best-located members (area of 90% confidence ellipse less 78 km^2, equivalent to a circle with 5 km radius) of the 1997 Jiashi swarm in western China. Relative locations from HDC analysis, with the entire cluster is shifted in space and time (10.4 km at an azimuth of 18°; 2.8 second earlier origin time) from the HDC solution to best match the one cluster event for which a reference location is available. Tics are in 0.1 deg.

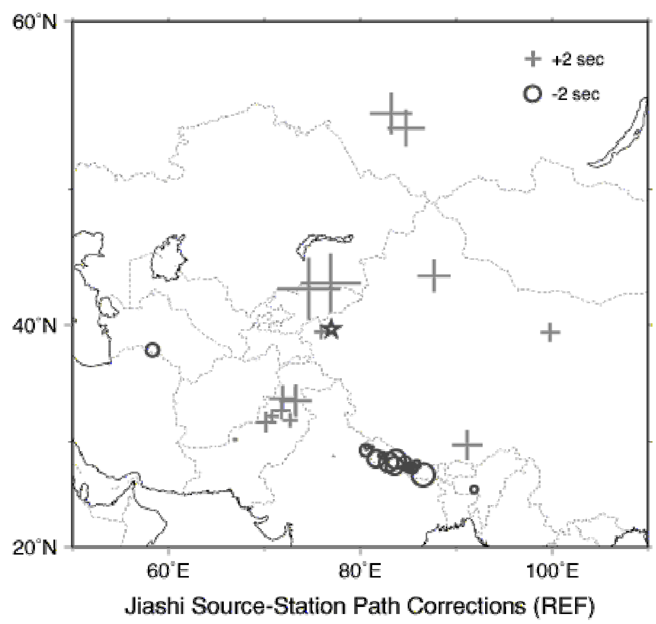

Figure 4. Source-station Pn path corrections based on median residuals to stations using HDC locations with the centroid shifted to bring the cluster into agreement with the reference event (star). Only stations which observed at least 5 Pn arrivals and with standard errors of less than 0.5 sec are plotted.

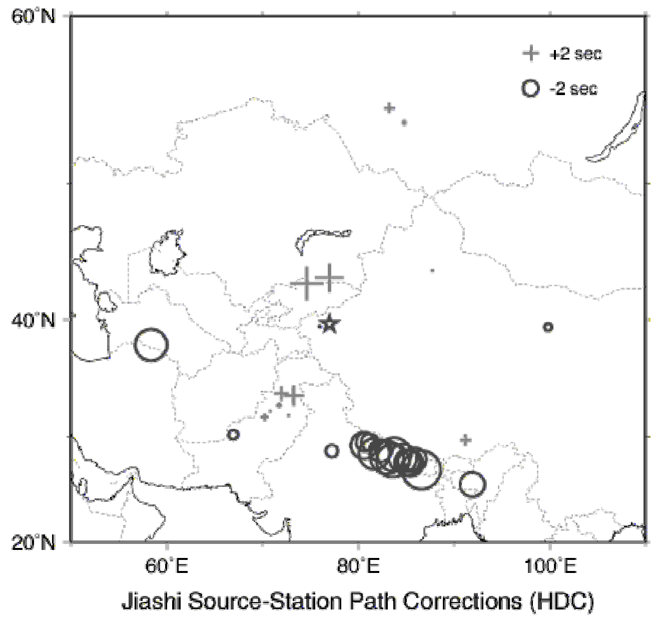

Figure 5a. Source-station Pn path corrections based on median residuals to stations using HDC locations. Only stations which observed at least 5 Pn arrivals and with standard errors of less than 0.5 sec are plotted. Star is location of reference event.

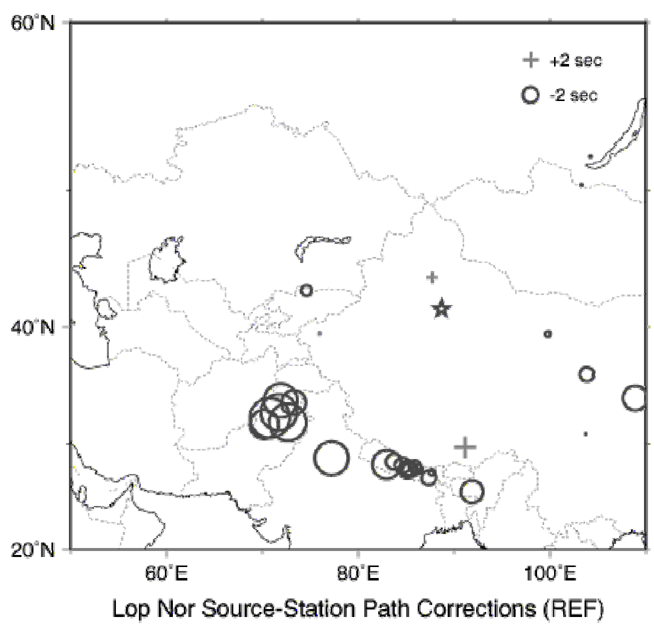

Figure 5b. Source-station Pn path corrections based on median residuals to stations using well determined Lop Nor explosion locations. Only stations which observed at least 5 Pn arrivals and with standard errors of less than 0.5 sec are plotted. Star is location of Lop Nor test site.