# GROUND TRUTH IN CENTRAL ASIA FROM IN-COUNTRY NETWORKS

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Sponsored by National Nuclear Security Administration
Office of Nonproliferation Research and Engineering
Office of Defense Nuclear Nonproliferation

Contract No. DE-FC52-04NA25541[1], W-7405-ENG-36[2]

## ABSTRACT

Our project involves improving the database of seismic event ground truth (GT) information for central and southern Asia using data from a recent broadband seismic experiment in Nepal and Tibet, supplemented by local network data and other regional data. We will develop a catalog of ground-truth events in central Asia where reference-event coverage is poor due to the limited station coverage. The GT catalog will include origin time, hypocenter, and focal mechanisms of well-recorded local events. The results of this project will enable the seismic monitoring community to enhance operational capability to monitor for nuclear tests in central Asia by calibrating station-centric correction surfaces and increasing the ability to accurately locate and identify seismic events in these regions.

The Himalayan Nepal Tibet Seismic Experiment (HIMNT) consisted of the deployment of 29 broadband STS2 seismometers throughout eastern Nepal and southern Tibet during 2001, 2002, and 2003. The network lies in a relatively unexplored but strategic position in close proximity to India, Pakistan, and parts of China. The dataset is unique with many stations in remote and difficult to access locations. Security concerns may limit future deployments in many of these regions. Ground-truth coverage in this region is sparse, and no permanent stations exist in most of the area covered by our array. To date, we have detected and located hundreds of high quality events from the HIMNT experiment using the dbloc2 and dbgenloc software of the Antelope database software. Refinement and validation of GT will be performed using advanced location algorithms (such as the National Nuclear Security Administration (NNSA) event location algorithm Loc00 and the three-dimensional (3D) nonlinear NonLinLoc algorithm), full waveforms, as well as joint inversion for earthquake location and 3D velocity structure. Given our station and event coverage, we are in a good position to determine local 3D velocity structure and to perform joint or iterative inversion for hypocenters and velocity structure. Development of the GT catalog will include supplementing the HIMNT data with that from other networks, collection of additional waveform data, picking of secondary phases, checking against teleseismically located events, and moment tensor and source parameter analysis of GT events (with particular attention to depth control).

Seismic waveforms are often difficult to obtain from sensitive areas. In this case, we have such waveforms in hand and are in a good position to apply and utilize advanced location, velocity structure, and source parameter algorithms. The high quality GT will be used to validate regional scale models for raypaths emanating from the study region, and will be used to validate and further calibrate station-centric correction surfaces that account for unmodeled travel-time variations. Although this is a small area compared to the breadth of the region of monitoring interest, results from deployments of this type may be optimal in terms of GT quality and expense. A number of efforts such as that described here will be necessary to provide high quality GT over broad areas; however, given the restrictions on data availability in the region, such an approach is of great value.

## OBJECTIVE

The goal of this project is to contribute to the database of ground truth seismic events in central Asia using data from the Himalayan Nepal Tibet Seismic Experiment (HIMNT) network and other regional seismic data.

## RESEARCH ACCOMPLISHED

### HIMNT Deployment

The Himalayan Nepal Tibet Seismic Experiment (HIMNT) was a National Science Foundation (NSF) and Incorporated Research Institutes for Seismology (IRIS) PASSCAL (Program for Array Seismic Studies of the Continental Lithosphere) deployment in Nepal and Tibet in 2001-2003 (Figure 1). HIMNT was the first broadband seismic experiment to simultaneously cover the plains of southern Nepal, the Lesser and Greater Himalaya, and the Southern Tibetan Plateau. The HIMNT experiment included the deployment of twenty-nine three-component broadband seismic stations, which recorded continuously at a sample rate of 40 sps. Though the project primarily has tectonic objectives, the high-quality data collected is ideal for ground truth data for monitoring purposes. HIMNT stations were installed with approximately 40-50 km station spacing, covering a two-dimensional area approximately 300 km wide east-west by 300 km north-south (Table 1). This geometry is well suited for both event location and seismic velocity structure projects. Station locations were dictated strongly by logistics, with some stations only accessible by air or by a several day hike on foot. Because of the political situation in Nepal many HIMNT stations would not be safe to redeploy today. Stations from other regional networks are shown in Figure 2, including the Bhutan PASSCAL deployment (e.g. Steck et al., 2004).

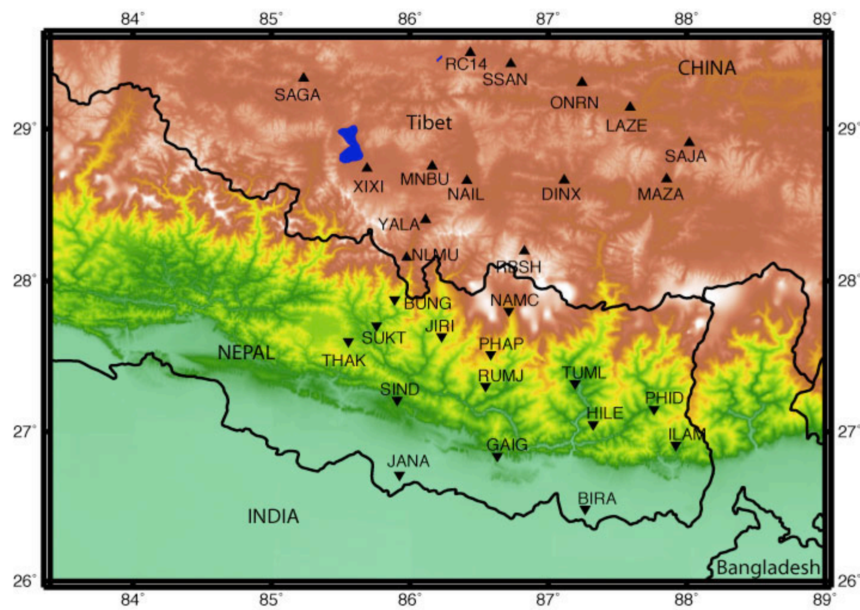


**Figure 1. Topographic map with broadband seismic stations of the 2001-2003 Himalayan Nepal Tibet PASSCAL Seismic Experiment (HIMNT).**

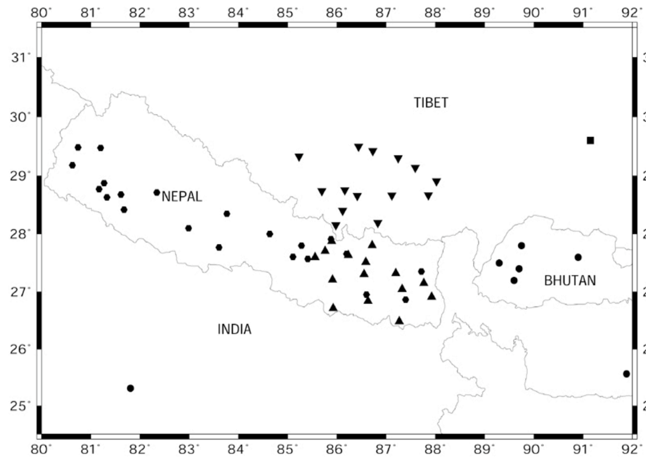


**Figure 2. Seismic stations in the vicinity of the HIMNT network. HIMNT stations (triangles), Nepal DMG (circles in Nepal), Bhutan PASSCAL (circles in Bhutan), Indian IMD (circles, more stations off map), GSN station LSA (square).**

## Data Quality

A background noise analysis for HIMNT stations has been performed (de la Torre et al., 2003). Power spectral density (PSD) estimates of background noise were calculated for all stations and compared to the High Noise Model (HNM) and Low Noise Model (LNM) of Peterson (1993) (Figure 3). All waveforms from designated day and night local time windows for twenty-one day time periods are included in the calculation without segregating events. Moderate noise levels are found for HIMNT stations, with all but the two southernmost stations falling within the HNM and LNM bounds. The southern Nepal (Terai) stations were installed in specially constructed above ground vaults because of the high water table, and exceed the HNM at frequencies greater than 1 Hz. The time period needed for sites to stabilize was found to be short, on the order of one week.

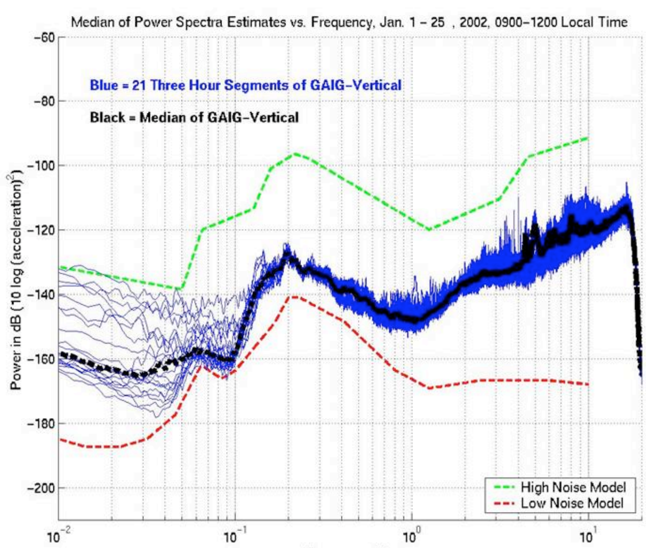


**Figure 3. Noise spectra at HIMNT station GAIG, vertical component, daytime. Noise spectrum is calculated for many 3-hour segments, shown, and the median of these segments is calculated. Dashed lines represent the High and Low Noise model of Peterson (1993).**

**Data Management**

The entire continuous HIMNT database has been organized using the Antelope software developed by Boulder Real Time Technologies (BRTT). This package includes software for waveform analysis, including picking and location algorithms. To facilitate first arrival picking, origin tables were made by merging the Nepal Department of Mines and Geology catalog, USGS NEIC catalog (with distance-magnitude criteria appropriate for our purposes), and an automatic event detection list. The automatic event detections are made by first applying STA/LTA criteria to the data to detect possible P-wave arrivals. The STA/LTAs are applied within several filter bands (0.5-1.2 Hz, 0.8-3 Hz, 3-10 Hz), with the STA/LTA window lengths and ratio varying with each filter band. Another algorithm is used to check for detections at several stations inside a given time window, and declaring a trigger if enough stations had a detection within a given time. For each trigger a preliminary location was determined using a grid search algorithm and the detection times. Our merged origin table consists of >10,000 triggers, of which approximately 20% are pickable events. For comparison, the NEIC PDE catalog for this time and area has 71 events (42 within our network footprint) (Figure 4).

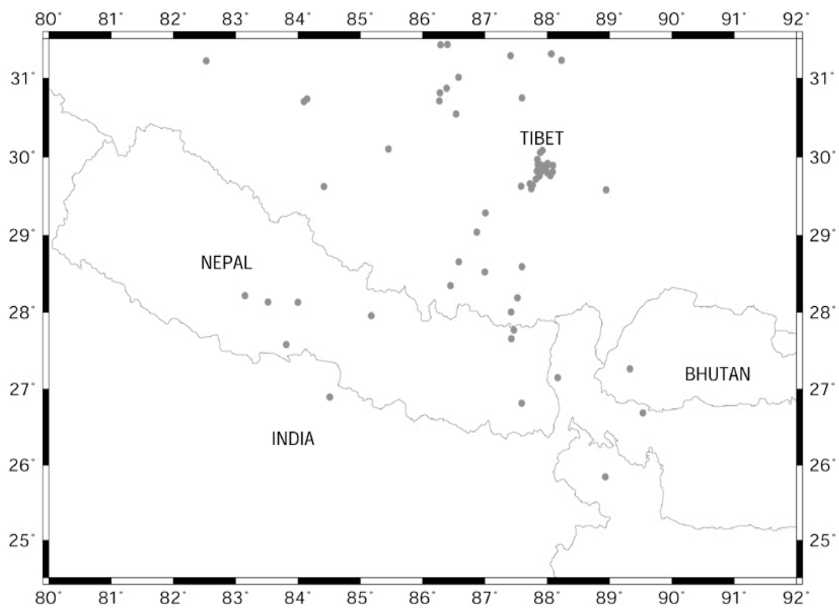


**Figure 4. NEIC PDE catalog of events in vicinity of HIMNT, Nov 2001-March 2003. Events depicted by circles, magnitude > 3.5. Our local HIMNT network catalog (in progress) has hundreds more earthquakes.**

**Waveform Picking**

For in-house processing, the data are reviewed by an analyst, with first arrival P-wave and S-wave picks made. Our database contains over 20,000 picks (P and S). Determination of preliminary event locations is underway using the dbloc2 interactive hypocenter location software. The dbloc2 software facilitates the location of hypocenters from picked trace data, while allowing interaction with the location program and the ability to edit arrival picks. The genloc event location library called from dbloc2 utilizes traditional iterative least squares inversion for event location, given station locations, phase arrival times and a velocity model. We use the Nepal velocity model of Pandey et al. (1995) and the southern Tibet velocity model of Cotte et al. (1999) depending upon earthquake location. The velocity models for Nepal and Tibet are dramatically different in terms of crustal thickness. An important part of our project involves dealing with location uncertainty in light of large structure and velocity contrasts, and modeling of lateral velocity variations in order to obtain well-constrained locations.

**Preliminary Locations**

From the 700 earthquakes located so far, we find a dense alignment of seismic events along the front of the High Himalaya (Figure 5). Many earthquakes cluster at 15-25 km depth beneath the High Himalaya of northern Nepal, and earthquakes with depths between 70-85 km are found in northeastern Nepal and southern Tibet. Many of the southern Nepal earthquakes are at depths close to the crust-mantle boundary. The double-difference algorithm HypoDD (Waldhauser and Ellsworth, 2000) has been used to relocate earthquakes, improving relative locations. After relocation, the alignment of earthquakes following the front of the High Himalaya is clearer, as well as clustering with depth. As seen by comparing Figures 4 and 5, the NEIC catalog has only a fraction of the events recorded by our network. While most of the best quality ground truth events are likely to be those that were large enough to be detected and reported by the NEIC, we are finding many excellent quality events between magnitudes 3.5 – 4.1 that are not in the NEIC PDE catalog (Figure 6). The number of potential ground truth events will increase when we consider the ISC catalog and our own HIMNT catalog, as well as the expanded network made possible through inclusion of complementary data from Bhutan (e.g., Steck et al., 2004) and regional stations.

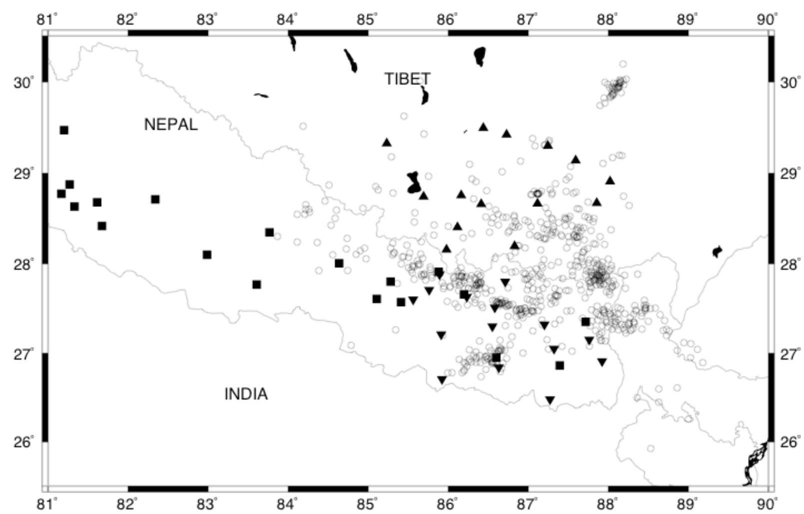


**Figure 5. HIMNT preliminary event locations. Events depicted by unfilled circles, seismic stations by solid symbols. HIMNT (triangles), Nepal DMG (squares).**

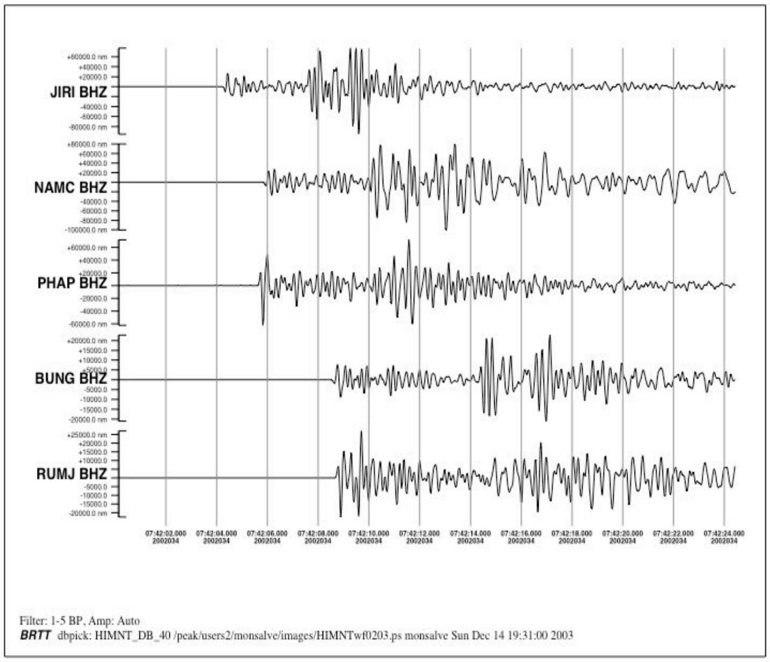


**Figure 6. Sample HIMNT seismograms for magnitude 4.1 earthquake of February 3, 2002. This high quality event does not appear in the NEIC PDE catalog. Vertical component at HIMNT stations JIRI, NAMC, PHAP, BUNG, and RUMJ. Closest station is JIRI, at a distance of 30 km. Bandpass filter band 1-5 Hz. Time between tick marks is 2 seconds.**

**Correction Surfaces and Seismic Event Relocations**

Incorporation of these new data will aid in the development and application of preliminary first-arrival P- and S-wave propagation path correction surfaces for regional stations used in seismic locations in Nepal, Tibet, or northern India. This method relies on empirical estimation of corrections that are applied to travel-time estimates in the location process; ground truth is therefore essential. The correction surface method has been shown to be successful in several studies, including those of Myers and Schultz (1998) in the Middle East, and Steck et al. (2001a and b) in Asia. Our approach will be to use the modified Bayesian kriging method currently used by the NNSA labs (Schultz et al., 1998). The method has been implemented in the NNSA kriging tool, Knowledge Base Calibration Integration Tool (KBCIT), and provides output suitable for use with EvLOC, LocOO and other NNSA location tools. GT events from this dataset will be seen at regional stations around Asia, and will be used for calibration of the correction surfaces. In a similar fashion, this GT will provide calibration for regional velocity models around Asia, not just within the study area.

Earthquake locations were initially determined assuming a velocity model with no lateral variations within the lithosphere. In order to account for this lateral heterogeneity, a joint inversion for hypocenter determination and 3D velocity structure will be performed. Given our station and hypocenter distribution, as well as the quality of the arrival time picks and waveforms, out data set is well suited for use of tomographic tools such as tomoDD (Zhang and Thurber, 2003).

## CONCLUSIONS AND RECOMMENDATIONS

Use of in-country networks contributes to ground truth location determination in central Asia, important for validation of regional velocity models and correction surfaces. Examination of data from the HIMNT network indicates a wealth of high quality events not indicated in global catalogs such as the NEIC PDE. In addition to detection and location, use of in-country networks will be utilized for source parameter estimation and for event depth determination. Such events are of utility for GT as well as for regional velocity structure, and will contribute to the NNSA Knowledge Base.

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**Table 1. HIMNT Stations ***

| Station name | Latitude, N | Longitude, E | Elevation (km) | Start date | End date |
|---|---|---|---|---|---|
| BIRA | 26.4840 | 87.2670 | 0.012 | 10/19/2001 | 11/10/2002 |
| BUNG | 27.8771 | 85.8909 | 1.191 | 10/13/2001 | 04/06/2003 |
| GAIG | 26.8380 | 86.6318 | 0.166 | 10/14/2001 | 06/03/2002 |
| HILE | 27.0482 | 87.3242 | 2.088 | 10/12/2001 | 11/06/2002 |
| ILAM | 26.9102 | 87.9227 | 1.181 | 10/17/2001 | 10/30/2002 |
| JIRI | 27.6342 | 86.2303 | 1.866 | 10/15/2001 | 10/22/2002 |
| NAMC | 27.8027 | 86.7146 | 3.523 | 10/21/2001 | 03/31/2003 |
| PHAP | 27.5150 | 86.5842 | 2.488 | 10/14/2001 | 04/01/2003 |
| PHID | 27.1501 | 87.7645 | 1.176 | 10/22/2001 | 10/31/2002 |
| RUMJ | 27.3038 | 86.5482 | 1.319 | 10/10/2001 | 04/03/2003 |
| SIND | 27.2107 | 85.9088 | 0.465 | 10/19/2001 | 04/03/2003 |
| THAK | 27.5996 | 85.5566 | 1.551 | 10/16/2001 | 11/07/2002 |
| TUML | 27.3208 | 87.1950 | 0.360 | 10/10/2001 | 04/03/2003 |
| LAZE | 29.1403 | 87.5922 | 4.011 | 07/21/2002 | 10/27/2002 |
| SAJA | 28.9093 | 88.0209 | 4.351 | 07/23/2002 | 11/07/2002 |
| ONRN | 29.3020 | 87.2440 | 4.350 | 07/13/2002 | 08/02/2002 |
| SSAN | 29.4238 | 86.7290 | 4.585 | 09/14/2001 | 09/08/2002 |
| SAGA | 29.3292 | 85.2321 | 4.524 | 09/16/2001 | 10/31/2002 |
| DINX | 28.6646 | 87.1157 | 4.374 | 09/26/2001 | 11/06/2002 |
| RBSH | 28.1955 | 86.8280 | 5.100 | 09/20/2001 | 05/21/2002 |
| NAIL | 28.6597 | 86.4126 | 4.378 | 06/26/2002 | 11/03/2002 |
| MNBU | 28.7558 | 86.1610 | 4.500 | 07/18/2002 | 11/05/2002 |
| YALA | 28.4043 | 86.1133 | 4.434 | 07/17/2002 | 11/04/2002 |
| XIXI | 28.7409 | 85.6904 | 4.660 | 07/15/2002 | 11/01/2002 |
| RC14 | 29.4972 | 86.4373 | 4.756 | 07/14/2002 | 10/28/2002 |
| MAZA | 28.6713 | 87.8553 | 4.367 | 07/24/2002 | 11/07/2002 |
| JANA | 26.7106 | 85.9242 | 0.077 | 11/13/2001 | 02/05/2003 |
| SUKT | 27.7057 | 85.7611 | 0.745 | 03/05/2002 | 11/07/2002 |

*Station NLMU did not have usable data and is not included.