THE CENTRAL ASIA REGIONAL WAVEFORM ANALYSIS KNOWLEDGE BASE

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ABSTRACT

A knowledge base of event source parameters, earth structure models, regional and teleseismic waveforms, modeling tutorials and regional phase attributes is being constructed that will be accessible using standard web browsers. Teleseismic source models are now being constructed for a catalog of 73 earthquakes larger than a magnitude 5.5 located within central Asia. These teleseismic models constrain event source depth, time function, and source mechanism so that broadband regional and local waveforms can be modeled. Of interest is the nature of broadband, regional seismic wave propagation for predicting relative amplitudes, complexity, and arrival times of major regional seismic phases that propagate within central Asia. Using a variety of regional waveform modeling techniques (e.g., surface wave dispersion and "phase-time" inversion) 1D regional crust and upper mantle models are being developed that predict the observed waveforms. The learned experience in building these models and geophysical parameters derived from the waveform modeling are then incorporated into a knowledge base. The knowledge base can be browsed by seismic analysts who may be interested in learning about wave propagation in a particular region, seismic source characteristics, or attributes of past-observed seismograms that may be used to understand future unknown events. The web system is being constructed using the mySQL database manager as event data and event analyses become available. The final system will consist of a series of web pages, for each event, with text and graphics describing basic data, derived parameters, earth structure models, the modeling process, phase characteristics, etc. In addition, the original binary data and resulting synthetic seismograms will be accessible through a Java application, called kseis, that performs many of the same functions as Lawrence Livermore National Laboratory's Seismic Analysis Code but is machine-independent.

OBJECTIVES

The overall objectives of this 2-year research program are to:

1) Determine waveform characteristics of earthquakes and explosions over a broad frequency band that can be used to locate and identify small seismic sources in central Asia;
2) Construct a waveform and source parameter database to be used to understand local/regional wave propagation in central Asia and to identify sources;
3) Construct an earth structure database for models of the crust and upper mantle that accurately predicts the waveforms for seismic sources in central Asia;
4) Construct a knowledge base system that links data, data-derived source models, data-derived structure models, and educational tutorials for understanding sources, structure, and wave propagation in central Asia.

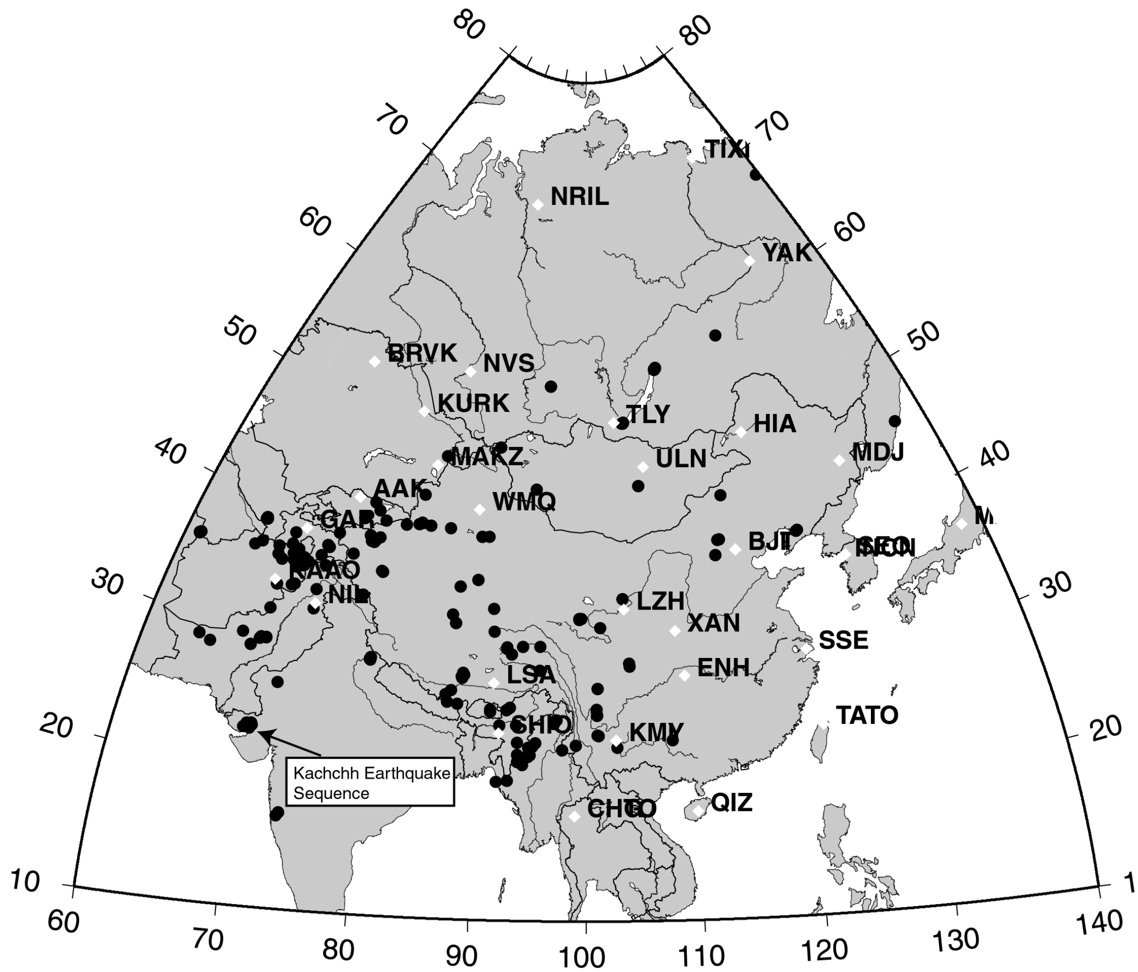

Figure 1. Map of central Asia showing station locations of the GSN and 375 earthquake events of mb greater than 5.0 from 1/01/98 to 6/01/01. The recent Kachchh earthquake sequence is annotated.

RESEARCH ACCOMPLISHED

Introduction

Work on this project can be usefully divided into two parts: "Scientific" and "Knowledge System".

The "scientific" work involves the collection, processing, and modeling of seismological waveform data for earthquake and explosion sources in central Asia. There are numerous technical issues that must be addressed to obtain accurate source parameters (such as source depth, focal mechanism, moment tensor, and time function) from teleseismic waveforms that can then be used to understand and model regional waveforms. The ultimate scientific product will be a set of one-dimensional (1D) earth structure models that can accurately predict the time and amplitude of major regional phases seen on seismograms from stations in central Asia. These regional models will allow insight on how regional waves propagate and lead to predictive hypotheses of what expected seismograms should look like for future events in the region.

The "knowledge system" work involves the manipulation of event catalog data, map displays, derived source parameters, derived earth structure parameters, graphical displays of data and synthetic seismograms, text-based tutorials, and relational databases in an html format that can be accessed by standard web browsers. In a very real sense, the knowledge system will be an interactive book that incorporates the data, scientific results, and scientific methods used to obtain those results. An interested seismic analyst or student can learn about particular earthquakes, particular regional earth structures, seismological techniques, wave propagation theory, or characteristics of observed seismograms. The knowledge system will integrate the scientific results of the project and be a self-teaching tool for use in the verification environment.

Effort in these two areas have natural separations but ultimately, the structure of the scientific problem defines how the knowledge system is to be constructed. The first year of work was spent in developing the tools for addressing the seismological analysis and also in developing the structure of the web-based "knowledge system".

Scientific Work Progress

The premises of the seismological study can be examined by considering a single earthquake event. Suppose an event occurs in central Asia, possibly in an area that is under suspicion for possible clandestine nuclear tests. Are there attributes of the regional seismic phases that can be used to determine the depth of the source or whether it is an explosion or an earthquake? Because it is likely that such events will be relatively small and not be observable at teleseismic distances, the only data that may be available will come from regional seismic stations at distances of hundreds to a thousand kilometers from the event. Thus, it is critical to know what regional seismic phases may be useful in estimating the possible source parameters and how those waves propagate in the region of interest. The well-known source/structure duality in seismology comes into play since the only way to infer the seismic source is to know the wave response of the structure.

The problem of regional seismic phase propagation has been around for many years mainly because large distances geographically separate earthquake sources and recording stations. It has been difficult to infer the earth structure wave response since the structure response has been masked by the (usually) unknown source excitation. Earthquake parameters, in particular, have been difficult to obtain since standard location procedures often cannot define source depth accurately enough and because there may be too few stations to infer a focal mechanism solution.

However, recent work with moderate earthquakes has shown that when the accurate source parameters are available, these source parameters may be effectively used to construct synthetic seismograms that accurately match observed regional seismograms. In a recent study of regional waves in Tanzania (Langston et al 2002), it was shown that a very simple crust and mantle structure could explain broadband regional waveforms out to distances of 900 km from the source. The timing of the regional phases yielded strong constraints on the average velocity structure of the crust and mantle and their amplitude and frequency content on the exact nature of the wave propagation. For example, the data showed clear multiple Sn phases associated with multiple S reverberations within the crust. Furthermore, the nature of the velocity gradient inferred in the crust and timing of the multiple S reverberations yielded a precise understanding into the nature of the Lg phase as high amplitude, high phase velocity turning waves in the crust. The relative timing of other phases, such as sPmP phases yielded estimates of source depth.

The key to understanding regional wave propagation is obtaining accurate source parameters for the regional events. In this research, we are concentrating first on examining moderate earthquakes (M5 and greater) within central Asia because it is possible to constrain source parameters with proven teleseismic body wave modeling techniques. Events of this size can be observed at teleseismic distances so that the source depth can be estimated accurately using the differential travel times of the direct wave and free-surface reflections and source mechanism from the waveform. In addition, the teleseismic P and S waveforms yield an important estimate of the far-field source time function that will be applicable to understanding the regional waveforms.

Using these source-constrained larger events, we will then be able to infer the physical mechanisms of regional wave propagation through analysis with synthetic seismograms as done in our previous African work. Using a variety of events with different source mechanisms and source depths, we expect to be able to characterize the crustal and upper mantle structure for many propagation paths in central Asia. These models will then be used to predict ground motions and model the source characteristics of smaller events in the same region.

During the first year's work, we have constructed several earthquake catalogs for events in central Asia. Shown in Figure 2 is a catalog of 73 events of M5.5 and greater from 1999-2003. Christy Chiu, the CERI seismic analyst working on this project, has produced an automated procedure to request data from all broadband stations within 90 degrees distance of the source that are archived by the Incorporated Research Institutes for Seismology (IRIS) Data Management Center. Data from these 73 events have been obtained and are archived on our SUN Microsystems computer network.

The data are transmitted to the Center for Earthquake Research and Information (CERI) by ftp and undergo a series of processing steps before analysis. A series of UNIX Cshell scripts are used to unpack the waveform data from the SEED volumes, correct individual broadband channels for instrument response (using Lawrence Livermore National Laboratory's (LLNL's) seismic analysis code (SAC)), rename channel files to a less cumbersome name, and rotate the horizontal component data into the theoretical backazimuth to the event to obtain radial and transverse ground motions. Christy Chiu also manually examines the data from each station to determine if a signal exists above the noise or if there are any other anomalous problems with the data. Acceptable data are then copied to separate UNIX file system directories for ground displacements and ground velocities. In addition, the data are segregated into a "teleseismic" directory for teleseismic waveform analysis and a "regional" directory for regional/local waveform analysis.

Once that data have been quality-checked and processed, a standard CSS3.0 schema database is built using the IRIS Datascope seismic database package. This software builds "flat" database files (simple ASCII files) that are incorporated into further seismic processing and modeling. Further processing for teleseismic waveform modeling includes calculating P and S wave arrival times and placing a marker into each waveform file for the particular arrival time. This is done using a short script and incorporates recent Java-based software provided by the University of South Carolina (the "TauP" travel-time package). The teleseismic P and S waveforms are then windowed from the three component data and modeled to determine the source depth, focal mechanism, moment tensor, and time function. Synthetic seismograms are computed using a Thompson-Haskell formulation for a point source in plane-layered media that incorporates teleseismic geometrical spreading for an appropriate whole-earth model, such as IASPEI91, and separate three-component receiver functions for each receiver.

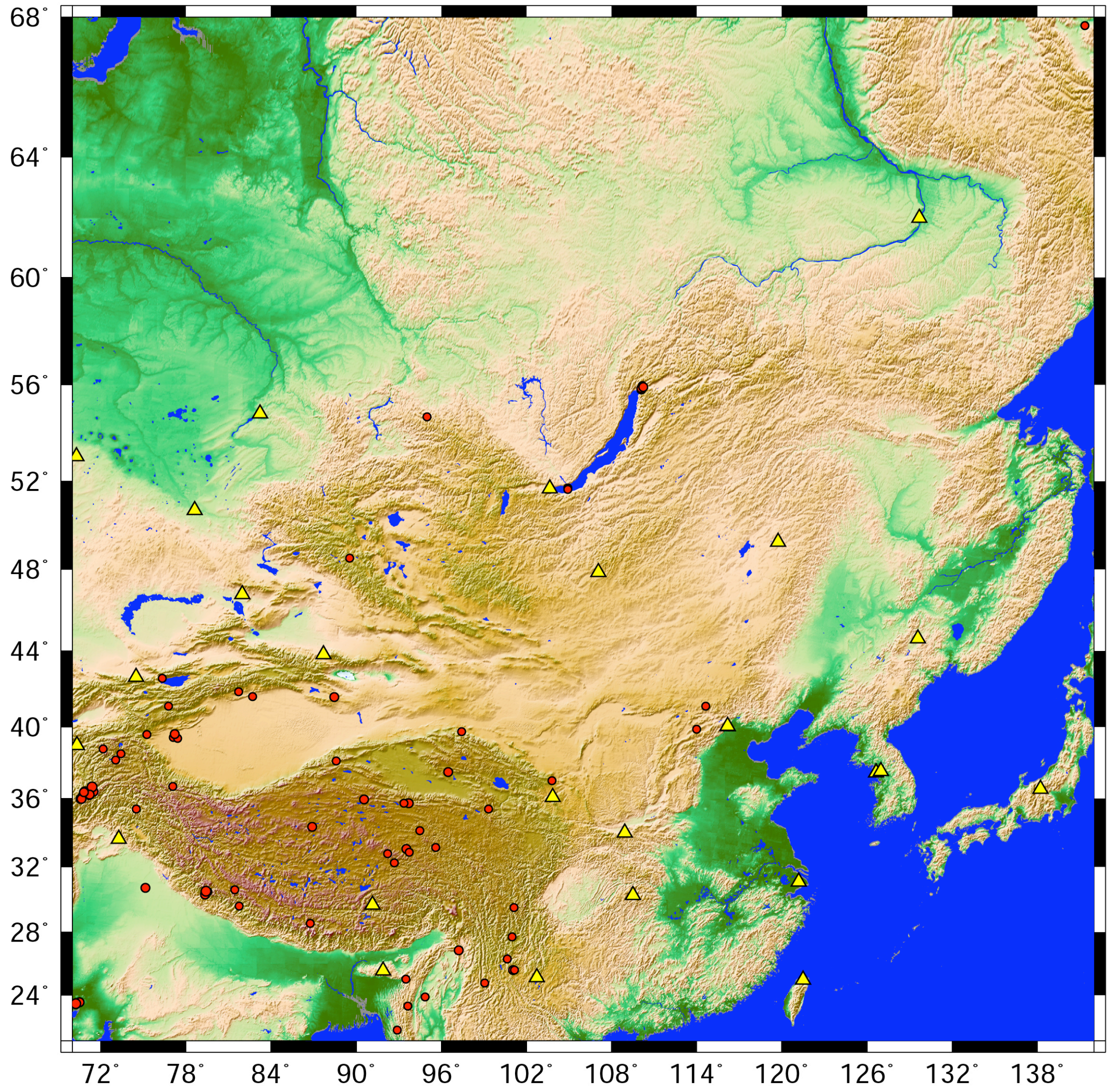

Figure 2. Map of central Asia showing the epicenters of 73 events of M5.5 or greater. The catalog search was for the time interval of 1/01/1999 to 5/31/2003.

Each of the events has 1 to approximately 10 stations that record the event within a regional or local distance. An examination of a few of these broadband waveforms shows that the regional wave propagation in much of central Asia seems similar to propagation in the Tanzanian craton. There are distinct, clear regional phases, such as PnL, Sn, and S multiples along with well dispersed surface waves for the shallow events. The surface waves afford a straightforward probe into average crustal structure through analysis and inversion of group velocity dispersion. The clear regional phases lend themselves to the newly developed "phase time" inversion where a simply-parameterized structure model is used to model the times and amplitudes of observed seismic phases through computation of accurate wave number synthetic seismograms.

Knowledge System Work Progress

Perhaps one of the most challenging parts of this project is the construction of the knowledge system that will bring the scientific results together into a unified framework. This system will ultimately consist of databases of source parameters, structure models, interactive graphical displays, and tutorials linked together in html format that can be accessed with common web browsers. In addition to the series of web pages there will be a facility where the broadband data and synthetics can be accessed through a Java program called "kseis" so that simple seismic analysis functions can be performed on the archived data independent of the type of computer used.

Work on the web page system has progressed such that we have solved the technical problems of linking diverse databases, text, and graphical objects. At the start of this project two of CERI's web designers, Kathy Tucker and Tanya Broadbent, suggested design ideas and web site structure. However, in January 2003, Ivan Rabak, a recent CERI master's graduate, joined the project half time to do the necessary programming to implement the system. His solution consists of using the openly available mySQL database management software with associated tools to create GUI's and scripts to incorporate seismic database results into the web page format.

The input and results of the scientific work will consist of

(1) event catalogs (location, date, origin time, and magnitude)
(2) station catalogs (location, and info)
(3) event source parameters (source depth, time function, mechanism, and errors)
(4) teleseismic event data and synthetic wave form graphics
(5) regional wave form data and synthetics graphics
(6) crustal and upper mantle structure models, tabular data, and graphics
(7) text tutorials (with graphics) on source modeling, structure modeling, and seismic phase results

The basic entry to the web system will be map based. Earthquake locations, station locations, and regional path results will be accessible, among other links, from a clickable base map. For example, Figure 3 shows the current rendition of the source map where each earthquake source can be accessed by the cursor and the source catalog data shown in a scroll box below the map. Buttons are available to zoom into the high resolution GTOPO5 map to pick an event epicenter. Each source point on the map and each entry in the catalog table are linked to other web pages that describe source modeling results. A similar page is available to describe seismic stations (represented as *yellow* triangles). Paths between sources and regional receivers will also be shown for individual regional sources. Clicking on a path will bring up the pertinent information on earth structure and regional waveform modeling that went into that path structure.

The database management software allows all and any of the data to be accessed either directly, as in the table example, or as links to other files, html documents, or graphic images. Currently we are incorporating the flat database files from the CSS3.0 database schema used in Datascope into the mySQL database manager through appropriate scripts so that the event results can be automatically converted into html format and a set of event web pages.

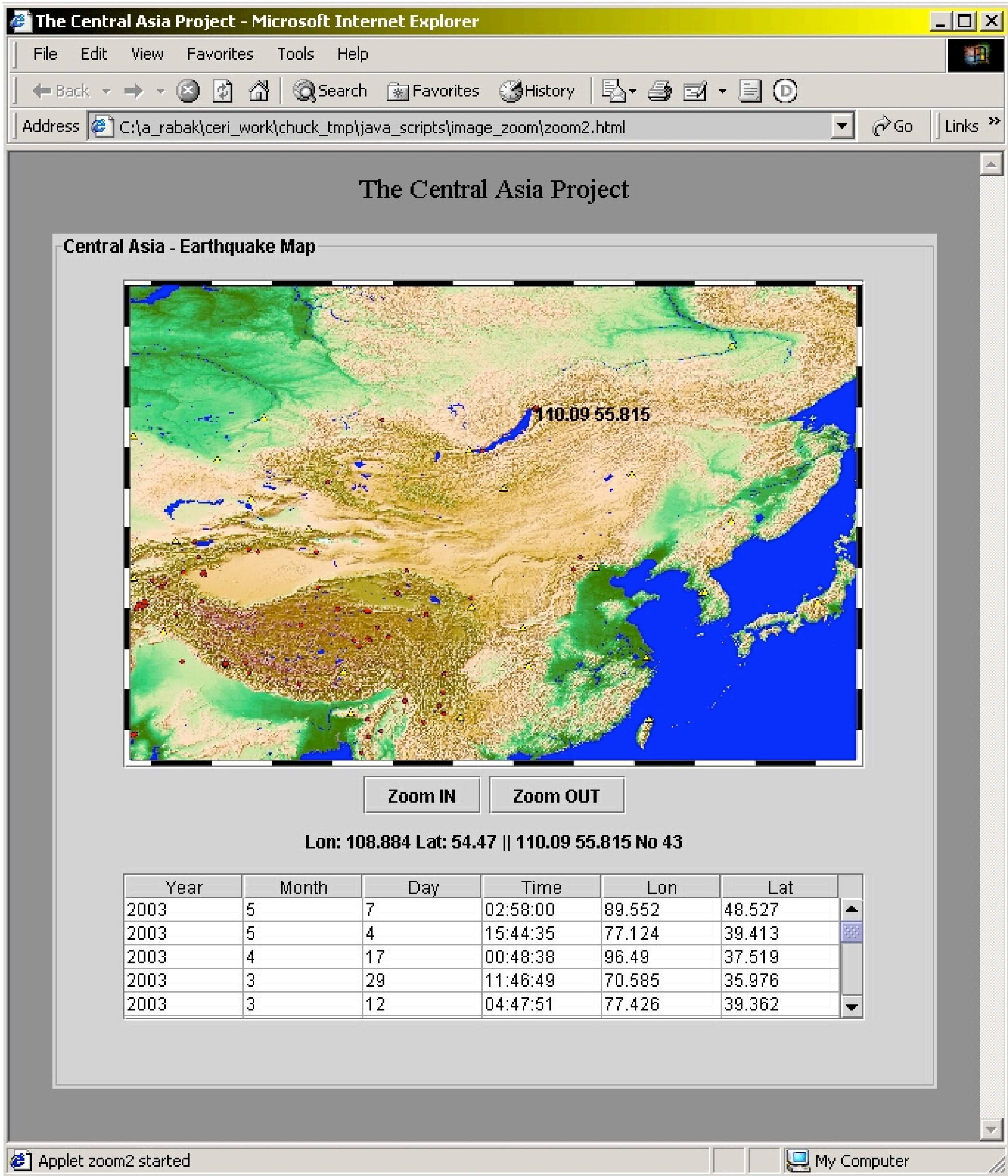

Figure 3. Example of the map interface used for accessing regional seismic sources.

Kseis Java Program

Daejin Kang has written a universal seismic data viewer that will be incorporated into the final knowledge system. This program, named "kseis", is written in Java and can be run on any machine with Java installed. This program can access SAC (LLNL seismic analysis code) binary file seismic data in either little endian or big endian byte format, display the data in a window, and perform various amplitude scaling, time picking, filtering operations, and particle motion analyses through button menus. Figure 4 shows an example of a PC-Linux system screen capture of the kseis waveform and seismogram information window. Shown are three components of broadband data, from the TIXI station in northern Siberia, from a central Asian event. The data waveforms can be examined by choosing a box around any phase to zoom in or out. Buttons along the top can be pushed to increase or decrease amplitude, move the seismograms in time, or expand/compress the time scale. Simple filtering operations, time differentiation, and time integration may also be chosen and there is a facility for removing instrument responses.

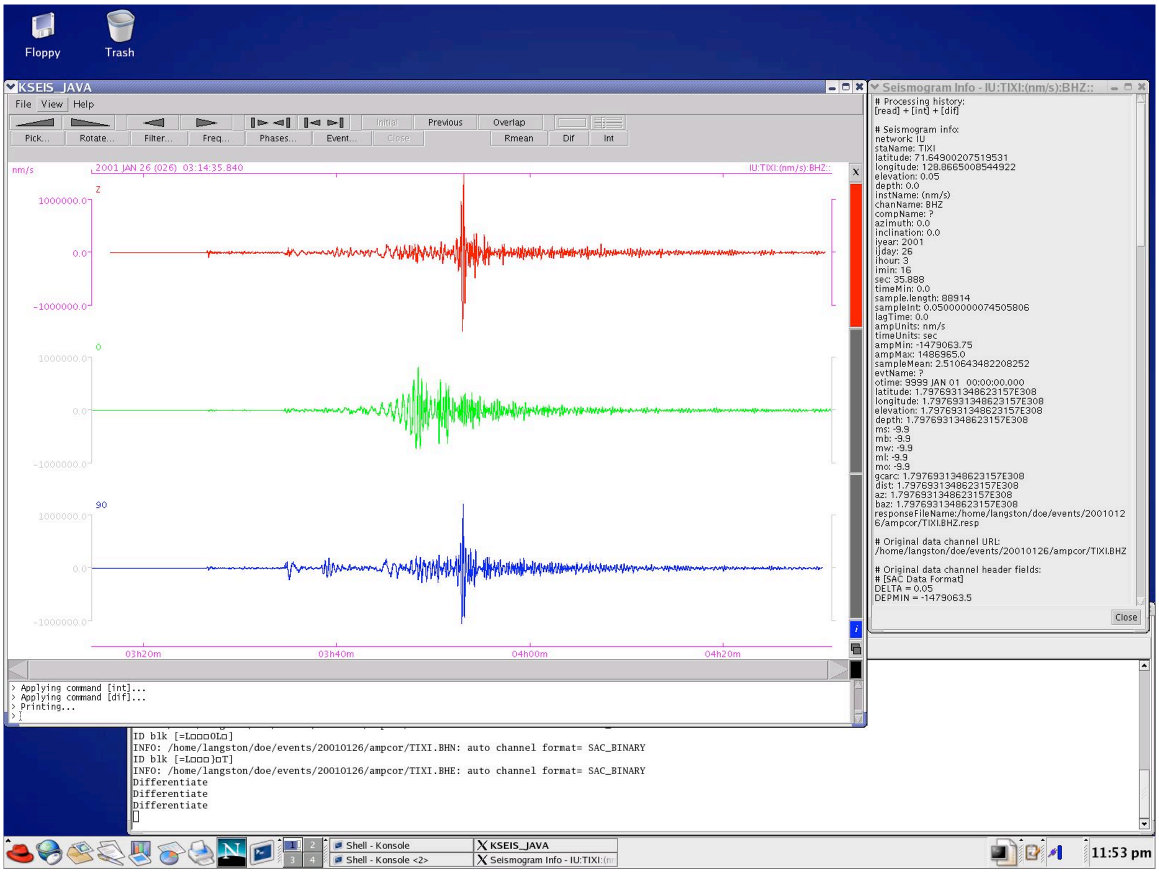

Figure 4. Screen capture jpeg showing the kseis seismogram analysis window and a pop-up window with the seismogram header information.

Figure 5 shows the particle motion plot where a perspective view is given for the three-component particle motion. The mouse can move this view for other perspectives, and time windows can be chosen for any sections of the seismogram. There is also a “movie” facility showing how a particle moves along the trajectory in time.

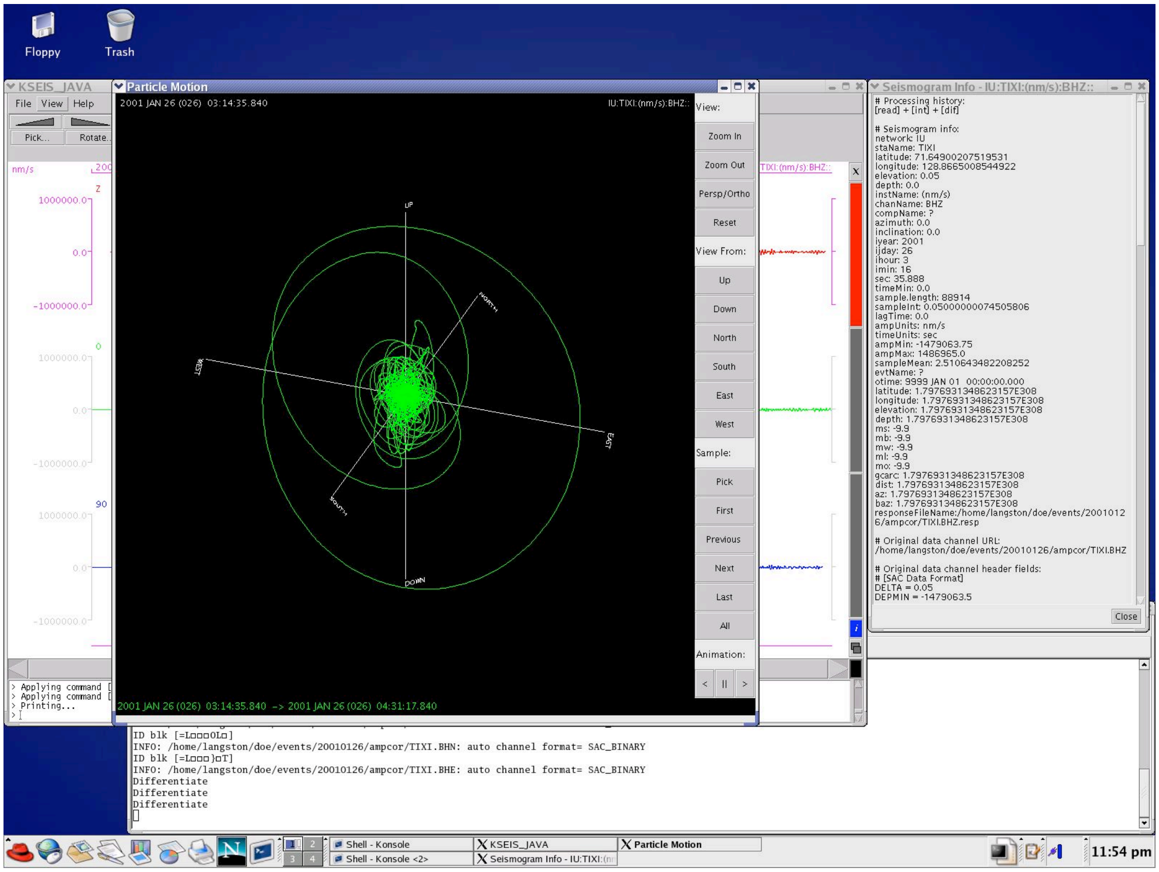

Figure 5. Screen capture showing the particle motion function in kseis.

Kseis is a natural utility to include with the knowledge base system for seismic analysts who want to examine the original seismogram data or any processed data or synthetic waveform. It is our intention to make the original waveform data available through the knowledge system with the kseis interface.

CONCLUSIONS AND RECOMMENDATIONS

Melding of scientific results and web-page presentation style should produce a useful research and information tool for the seismic analyst to use in understanding seismic sources in central Asia.

REFERENCE

Langston, C. A., A. A. Nyblade, and T. J. Owens (2002), Regional wave propagation in Tanzania, East Africa, *Jour. Geophys. Jour. Res.*, 107.