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PROTOTYPING REGIONAL DISCRIMINATION TOOLS WITH MATSEIS

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ABSTRACT

To facilitate the development, testing and comparison of regional seismic discriminants, we have implemented some of the most promising techniques in Matseis, a Matlab-based seismic processing tool kit. The existing Matseis package provides graphical tools for analyzing seismic data from a network of stations. It can access data via a CSS 3.0 database, or from static files in a format defined by the user. Waveforms are displayed in a record-section format, with overlays for IASPEI91 travel-time curves. The user can pick arrivals and locate events, then show the results on a map. Tools are available for spectral and polarization measurements, as well as beam forming and f-k analysis with array data. Additionally, one has full access to the Matlab environment and any functions available there, as well as to portions of the U.S. Department of Energy Knowledge Base.

Recently, we have added some new tools to Matseis for calculating regional discrimination measurements. The first of these performs Lg coda analysis as developed by Mayeda and coworkers at Lawrence Livermore National Laboratory (LLNL). Lg coda magnitudes are calculated from the amplitudes of the coda envelopes in narrow frequency bands. Ratios of these amplitudes between high- and low-frequency bands provide a spectral-ratio discriminant for regional events.

The second tool we have implemented measures P/Lg phase ratios, using the MDAC technique of Taylor (Los Alamos National Laboratory) and Walter (LLNL). P and Lg amplitudes are obtained at select frequencies, then corrected for source magnitude and propagation path. Finally, we added a tool for analyzing long-period Rayleigh and Love arrivals, useful for moment:magnitude and LQ:LR discrimination. Because all these tools have been written as Matlab functions, they can be easily modified to experiment with different processing details. The performance of the discriminants can be evaluated using any event available in the database.

Key Words: data processing and analysis, regional discrimination

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OBJECTIVE

Effective verification of the CTBT will require the implementation of reliable regional seismic discriminants. Processing details for event identification – including algorithms, their parameters and the decision thresholds – will certainly vary with geologic setting. The Knowledge Base effort of the DOE CTBT Research Program will provide a mechanism for storing and retrieving such region-specific information. Software tools which an analyst employs to characterize a seismic event will connect to the Knowledge Base to obtain the appropriate information based on the source location and the stations available.

We have begun adding some of the more promising regional discriminants to MatSeis, a seismic analysis toolkit based on MATLAB®. The objectives of this effort are twofold. First, it should facilitate the testing and refinement of the routines. Graphical interfaces will make the discriminants easier to use and accessible to a wider audience; the inherent flexibility and openness of MATLAB will simplify the process of modifying and tuning the functions. Second, MatSeis will provide the connection to the Knowledge Base, so that the discriminants can be properly configured for a given region.

RESEARCH ACCOMPLISHED

The MatSeis seismic processing toolkit was developed at Sandia to support CTBT R&D on improving event association and location (Harris and Young, 1997). Through menus in the MatSeis user interface, a researcher can connect to a CSS 3.0 database and select events, arrivals and waveforms for analysis. Once the desired data have been obtained, the waveforms can be displayed as a record section, with signals from the various stations organized vertically based on their epicentral distance (Figure 1). Selected travel-time

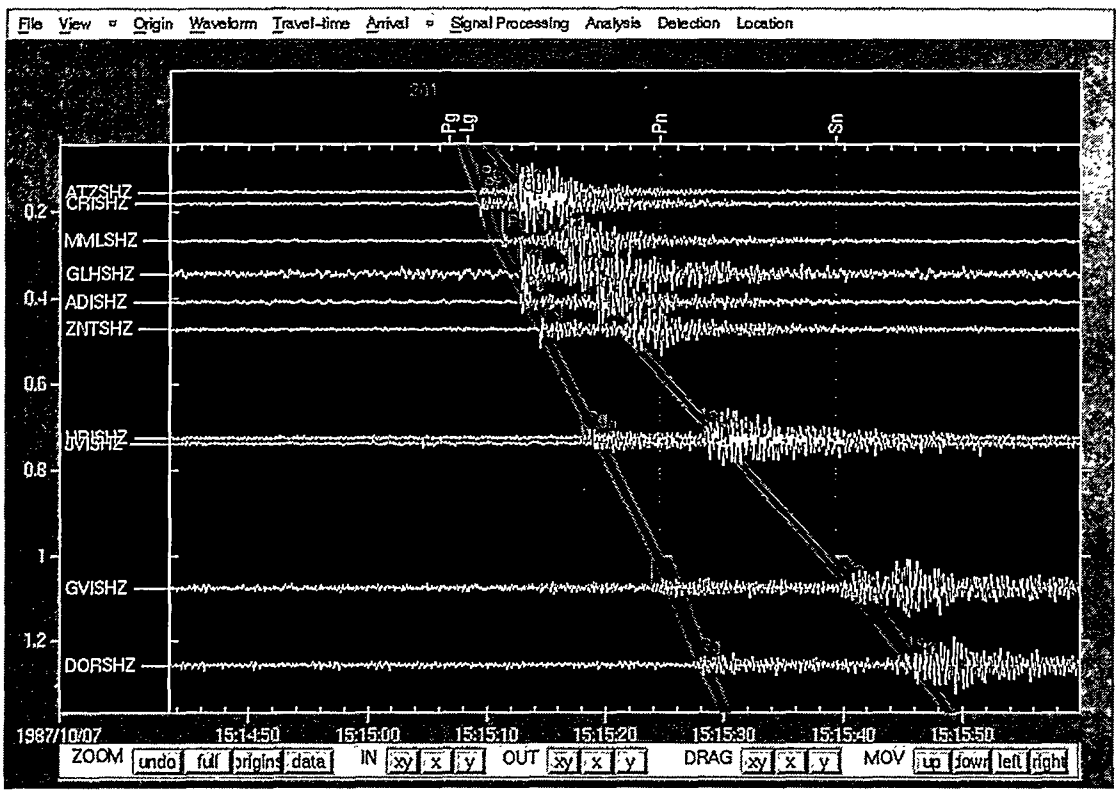

Figure 1. The main MatSeis screen.

curves may be overlaid on the plot, to assist in identifying phases. The package then provides a wide assortment of functions which the user can employ to assist in interpreting the signals and hence characterizing the event. A variety of filters can be applied to the signals. Arrivals can be picked or retimed, then their amplitude and period may be measured. The user may relocate the event via an interface to a location routine descended from TTAZLOC (Bratt and Bache, 1988), and display station and event positions on a map through an interface to the M_Map mapping toolbox (Pawlowicz, 1998). Modules are included for spectrum estimation, waveform correlation, polarization analysis, beamforming and frequency-wavenumber analysis. MatSeis serves as a key tool for developing and testing the DOE Knowledge Base, a system for storing and accessing region-specific information. Thus the analysis functions in MatSeis can exploit the contents of the Knowledge Base to optimize their performance in a given geographic area.

Written in the MATLAB® language, MatSeis can be readily modified or extended to include new functionality, so it serves as a very convenient prototyping platform for developing and testing new algorithms. Because of this inherent flexibility, and the developing access to region-specific information in the DOE Knowledge Base, we believe that MatSeis provides a suitable platform for testing and comparing regional discrimination algorithms. We have incorporated new modules for three candidate discriminants into MatSeis. These modules provide easy-to-use interfaces for performing the required measurements, with consistent implementation of common processing steps such as defining time windows and selecting frequency bands. The discriminants included so far include Lg coda analysis of Mayeda and coworkers, the P/Lg phase ratio technique of Taylor and Walter, and long-period Rayleigh and Love wave interpretation.

Mayeda has developed an approach for obtaining stable single-station Lg magnitudes from the decay of the Lg coda (Mayeda, 1993; Mayeda and Walter, 1996). A regional seismogram is filtered with a series of narrowband Butterworth filters and envelope functions are generated from each filter output. The coda behind the Lg onset is then modeled for each band using either a parametric form or an empirical envelope based on prior data from the station. The median log difference between the modeled and observed envelopes across the coda window then provides a spectral estimate at the center frequency of each filter. The energy in this source spectrum between 1.2 and 2.2 Hz is converted to an Lg coda magnitude. Finally, the ratio between the energy densities at low and high frequencies provides a discrimination measure (Mayeda and Walter, 1995). At the Nevada Test Site, explosions tend to produce weaker high-frequency Lg signals than earthquakes with similar low-frequency content.

To begin Lg coda analysis in MatSeis, the user first selects from the main screen an event and one or more stations at regional distance. When the Lg coda tool is chosen from the menu, the Lg coda GUI appears (Figure 2). The waveform window of this tool displays a seismogram, with default time intervals for Lg coda and pre-P noise highlighted. These time intervals can be modified as desired by dragging the highlight boxes along the waveform. From the interface, the analyst selects the desired station, channel and frequency bands. Additional parameters for the analysis are adjusted by editing a setup file. As parameters change, the coda spectral estimates and the magnitude and discrimination results are automatically updated.

The most promising regional discriminants appear to be those based on comparing the Lg arrival to either Pn or Pg (Walter *et al.*, 1995; Taylor, 1996). Taylor and Hartse (1998) have shown that corrections for source magnitude and the propagation path improve the ability of P/Lg ratios to separate earthquakes and explosions. More recently, Taylor *et al.* (1999) have refined the procedures for calculating these discriminants. Their method is known as Magnitude and Distance Amplitude Corrections, or MDAC. Smoothed spectral estimates are obtained for each arrival window. Corrections for event magnitude and the source-receiver path are then applied to the measurement for each phase at each desired frequency. The magnitude correction accounts for the change in corner frequency with event size. The path correction assumes frequency-independent geometric spreading, and attenuation due to a Q that varies as a power of frequency. Parameters for the source and propagation models in any region are empirically derived. The discriminant value is subsequently obtained by ratioing the corrected P and Lg amplitudes for a given frequency.

The MatSeis tool for P/Lg discrimination is shown in Figure 3. As with the Lg coda tool, one begins by

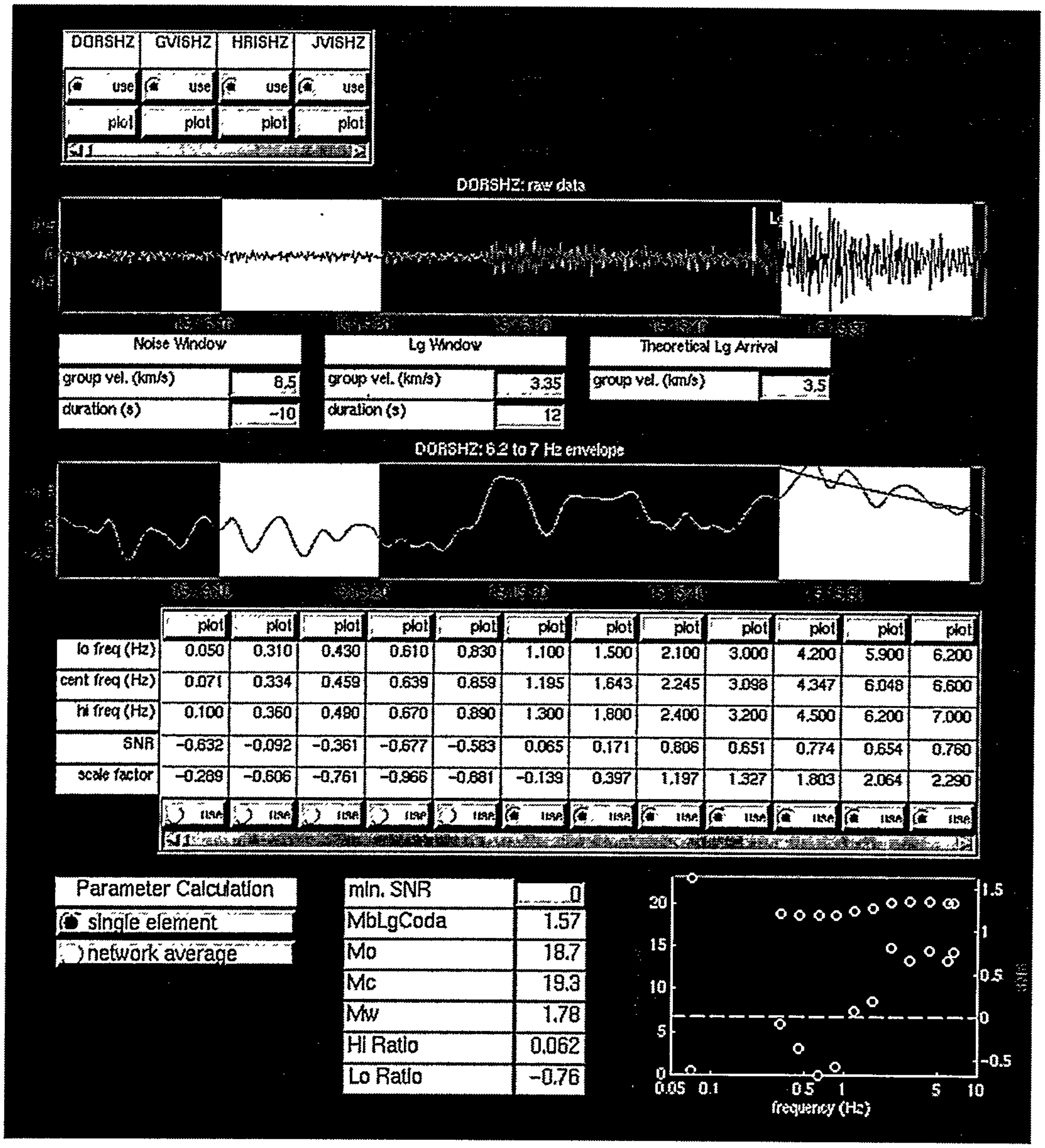

Figure 2. User interface for Lg coda analysis.

selecting an event and some regional stations in the main MatSeis window. Arrival and noise windows are extracted for analysis, and the resulting discrimination ratios are calculated. The interface shows the seismogram for a selected station and the spectra obtained from its arrival and noise windows. The Pn/Lg and Pg/Lg ratios for specified frequency bands are displayed in two plots, one for the current station, another for average results among multiple stations. Calculations can be performed in either the time domain, using narrowband filters and mean squared amplitudes, or the frequency domain, using FFTs.

The third discrimination tool we have implemented facilitates the analysis of long-period Love and Rayleigh arrivals. This tool has no distance restrictions, but can be invoked for any station with three-component, long-period or broadband records. For a selected station, the horizontal channels are first rotated to radial and transverse directions. Love (LQ), Rayleigh (LR) and noise windows are denoted using appropriate group velocities. The routine next calculates envelope functions for the bandpass-filtered records, then measures the peak amplitudes over the specified arrival windows. Signal-to-noise ratios for LQ and LR are determined, and the discrimination measure is simply the log of the ratio of the LQ and LR amplitudes. Explosive sources typically produce low values for this discriminant, because of their weak Love waves.

A primary motivation for adding these discriminants to MatSeis is to enable easy modification of processing parameters, and even of the algorithms themselves. This capability should simplify the task of optimizing the discrimination procedures for different regions. With multiple methods available in a common environment, one can more readily compare and contrast them, to understand their relative strengths. Combining the evidence from a variety of discriminants should improve the reliability of regional event identification.

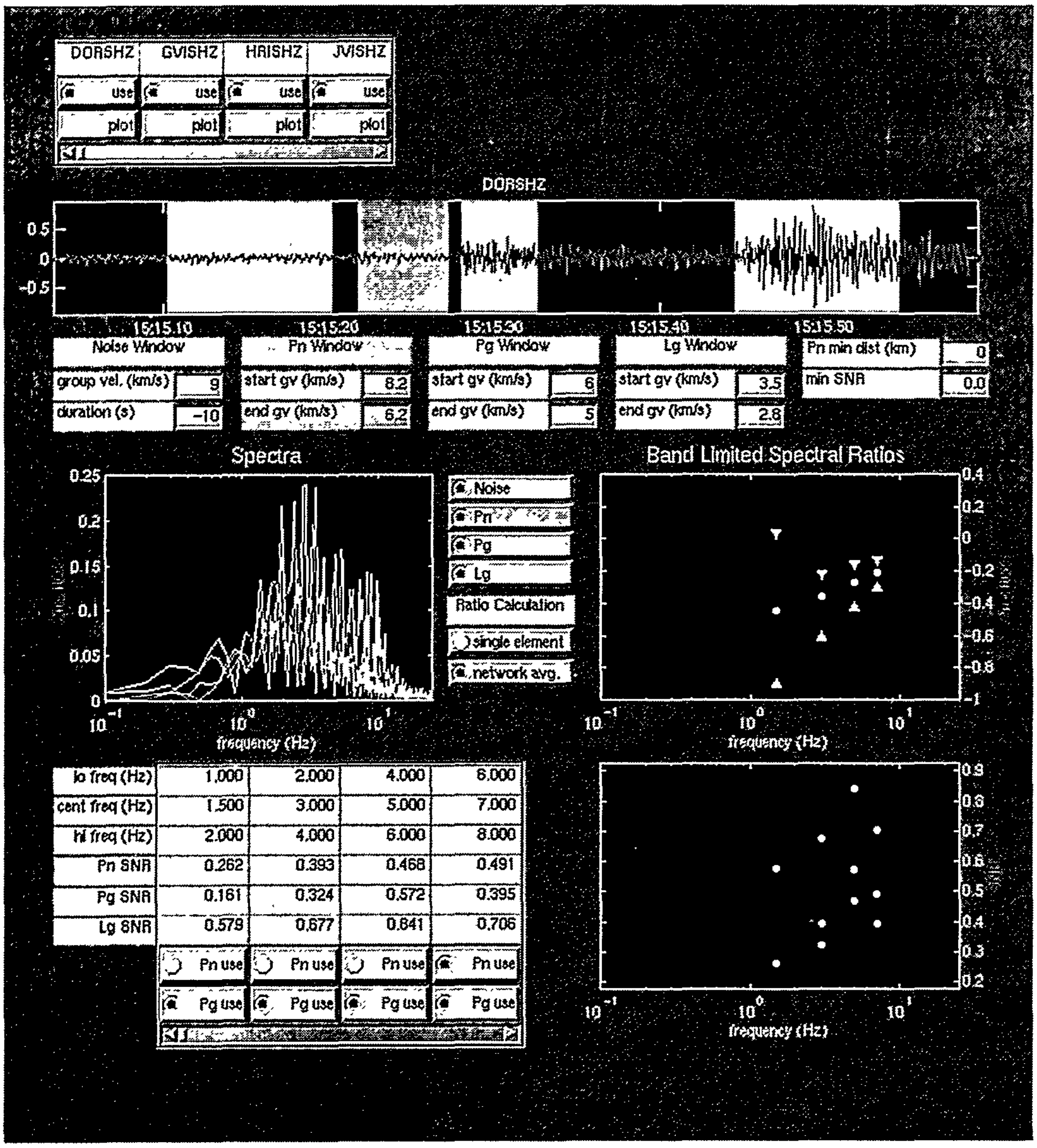

Figure 3. User interface for the P/Lg discriminant.

CONCLUSIONS AND RECOMMENDATIONS

We have implemented some promising regional discrimination algorithms as MATLAB functions, and developed easy-to-use graphical interfaces to them which can be invoked from MatSeis. As a result, a user can apply these discriminants to any event available in a CSS database, and exploit the appropriate region-specific information stored in the DOE Knowledge Base. We plan to add the capability to show results from selected reference events, so that one may observe a new event's relationship to prior activity in the region. As the Knowledge Base matures, we will enhance these tools to take advantage of more of the information stored there.

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