

## **SURFACE WAVE SIMULATION AND PROCESSING WITH MATSEIS**

Beverly D. Thompson, Eric P. Chael, Chris J. Young, William R. Walter<sup>1</sup>, and Michael E. Pasyanos<sup>1</sup>

Sandia National Laboratories and <sup>1</sup>Lawrence Livermore National Laboratory

Sponsored by U.S. Department of Energy  
Office of Nonproliferation Research and Engineering  
Office of Defense Nuclear Nonproliferation  
National Nuclear Security Administration

Contract No. DE-AC04-94AL85000

### **ABSTRACT**

In order to exploit the information on surface wave propagation that is stored in large seismic event datasets, Sandia and Lawrence Livermore National Laboratories have developed a MatSeis interface for performing phase-matched filtering of Rayleigh wave arrivals. MatSeis is a MATLAB-based seismic processing toolkit which provides graphical tools for analyzing seismic data from a network of stations. Tools are available for spectral and polarization measurements, as well as beam forming and f-k analysis with array data, to name just a few. Additionally, one has full access to the MATLAB environment and any functions available there. Previously we reported the development of new MatSeis tools for calculating regional discrimination measurements. The first of these performs Lg coda analysis as developed by Mayeda and coworkers at Lawrence Livermore National Laboratory. A second tool measures regional phase amplitude ratios for an event and compares the results to ratios from known earthquakes and explosions.

Release 1.5 of MatSeis includes the new interface for the analysis of surface wave arrivals. This effort involves the use of regionalized dispersion models from a repository of surface wave data and the construction of phase-matched filters to improve surface wave identification, detection, and magnitude calculation. The tool works as follows. First, a ray is traced from source to receiver through a user-defined grid containing different group velocity versus period values to determine the composite group velocity curve for the path. This curve is shown along with the upper and lower group velocity bounds for reference. Next, the curve is used to create a phase-matched filter, apply the filter, and show the resultant waveform. The application of the filter allows obscured Rayleigh arrivals to be more easily identified. Finally, after screening information outside the range of the phase-matched filter, an inverse version of the filter is applied to obtain a cleaned "raw" waveform which can be used for amplitude measurements.

Because all the MatSeis tools have been written as MATLAB functions, they can be easily modified to experiment with different processing details. The performance of the propagation models can be evaluated using any event available in the repository of surface wave events.

**Key Words**: data processing, data analysis, surface waves

## **OBJECTIVE**

Though improved regional discriminants are desirable for identifying small seismic events, Ms:mb remains as a preferred method when Rayleigh arrivals are recognizable. Phase-matched filtering (Herrin and Goforth, 1977) is a well-established method for enhancing and extracting Rayleigh waves from records of located events. This technique requires a reasonably accurate estimate of the Rayleigh dispersion along the path from event to station. Better models of surface-wave propagation at global and regional scales are now available (eg, Stevens and Adams, 1999; Pasyanos et al., 1999). These models have become sufficiently mature to enable the routine use of phase-matched filtering, which should permit reliable Ms measurements down to lower magnitudes.

To facilitate surface-wave analysis and Ms estimation, we have added an interactive phase-matched filtering capability to MatSeis, a seismic toolkit based on MATLAB. Graphical interfaces make the surface wave analysis routines easier to use and accessible to a wider audience. The user can select among different surface-wave propagation models to evaluate their appropriateness for an observed Rayleigh arrival. In addition, the inherent flexibility and openness of MATLAB simplifies the process of developing and modifying the algorithms. MatSeis provides connections to a repository of surface wave data so that phase-matched filtering can be performed for any events and waveforms stored there.

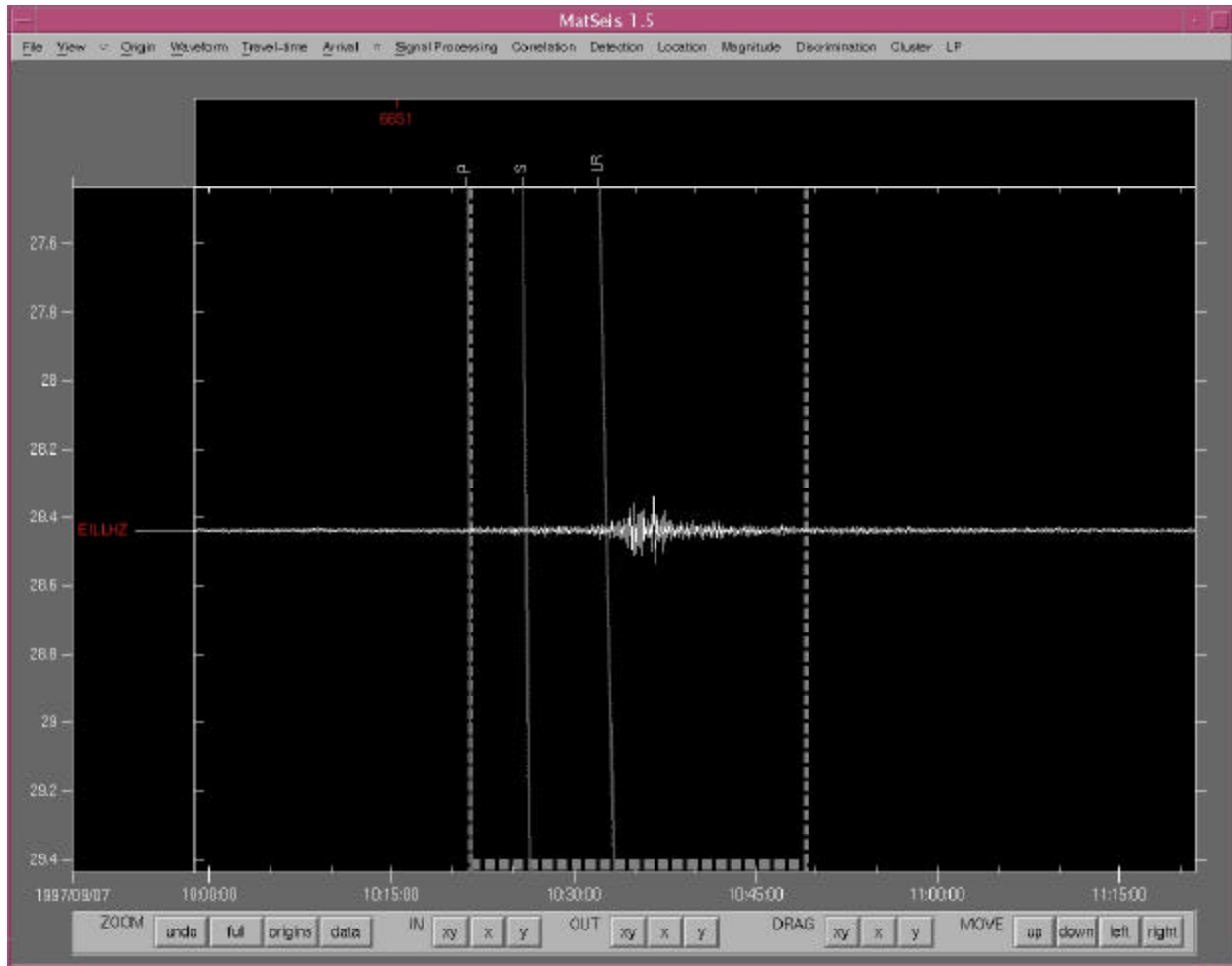
## **BACKGROUND**

The MatSeis seismic processing toolkit was originally developed at Sandia to support Comprehensive Test Ban Treaty (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 repository of surface wave data and select events, arrivals and waveforms for analysis. Once the desired data have been obtained, the waveforms can be displayed as a record section for any event, with signals from the various stations organized vertically based on their epicentral distance (Figure 1).

Selected travel-time curves may be overlaid on the plot, to assist in identifying phases. The package provides a wide assortment of functions to help the user interpret the signals and hence characterize 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 using an interface to a location routine descended from TTAZLOC (Bratt and Bache, 1988), and display station and event positions on a map through a connection 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 for optimal performance in a given geographic area.

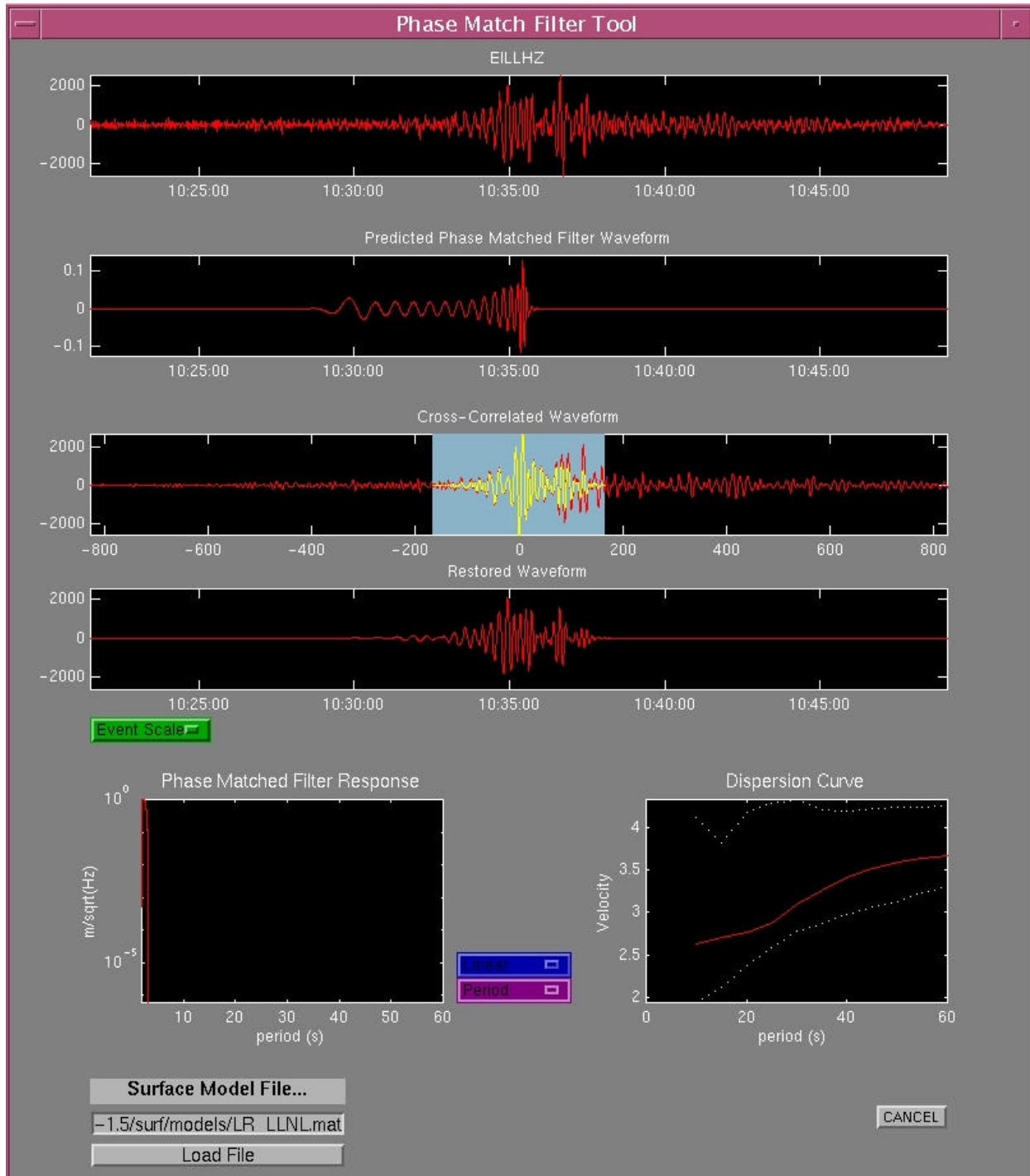
Written in the MATLAB<sup>®</sup> language, MatSeis can be readily modified or extended to include new functionality, so it serves as a convenient platform for prototyping new algorithms. Because of this inherent flexibility, and the access to region-specific information in the DOE Knowledge Base, we believe that MatSeis provides a suitable environment for analyzing long-period surface-wave arrivals as well. Previously we reported the development of MatSeis tools for calculating regional discrimination measurements (Chael et al., 1999). The first of these performs Lg coda analysis as developed by Mayeda and coworkers at Lawrence Livermore National Laboratory. The second measures amplitude ratios among regional arrivals for an event and compares the results to those from known earthquakes and explosions.



**Figure 1. MatSeis Main Window Display**

## **RESEARCH ACCOMPLISHED**

The current Release 1.5 of the MatSeis package includes new tools for the analysis of surface wave arrivals. These routines can generate phase-matched filters for any desired path, given a 2D model of Rayleigh group velocity distribution. So far we have incorporated a regionalized model of the whole earth (Stevens and Adams, 1999), a tomographic model for the Middle East and North Africa (Pasyanos, 1999), as well as individual dispersion curves for some specific paths from the Lop Nor (China) test site. For each frequency available in the chosen model, the travel time over the great circle from source to receiver is determined by following the path through the model grid, and looking up the tabulated group velocity for each cell traversed. The resulting path-average dispersion curve is plotted along with the maximum and minimum group velocities in the grid at any frequency. Next, the path-average curve is used to create a phase-matched filter, using Equation 4b of Herrin and Goforth (1977). We chose to calculate the correlation form of this filter, so that its waveform is effectively a unit-amplitude synthetic, which can be directly compared to the recorded signal. Correlating this filter with the seismogram should result in a peak near zero lag if the synthetic and observed waveforms agree, assuming there is sufficient signal energy relative to the noise in the data. Finally, a window around the peak in the cross-correlation function can be extracted, then convolved with the phase-matched filter. This redisperses the energy, which should produce a restored version of the original signal with reduced noise, and hence a cleaner Rayleigh arrival.



**Figure 2. Phase Match Tool with ray traced path using LLNL Model.**

To begin surface wave analysis in MatSeis, the user first selects from the main display one event and one long-period waveform, identified by its station and channel codes. Next a time window spanning the expected Rayleigh arrival is marked (the vertical dashed lines in Figure 1). When the 'Phase Match Tool' is chosen under the 'LP' menu, the user interface shown in Figure 2 appears. The topmost waveform displays the selected seismogram of the event from the main MatSeis window. The phase-matched filter for this source-station path is shown below this, plotted on the same time axis. The third waveform represents the cross-correlogram of the data and the filter, centered on a lag

time of zero. The blue box on this plot highlights the segment of the correlogram to be extracted and redispersed. By clicking and dragging with the mouse, the user can move and resize the blue box to extract any desired portion of the trace. The restored waveform, fourth from the top, shows the result of convolving the correlogram segment within the blue selection box with the phase-matched filter.

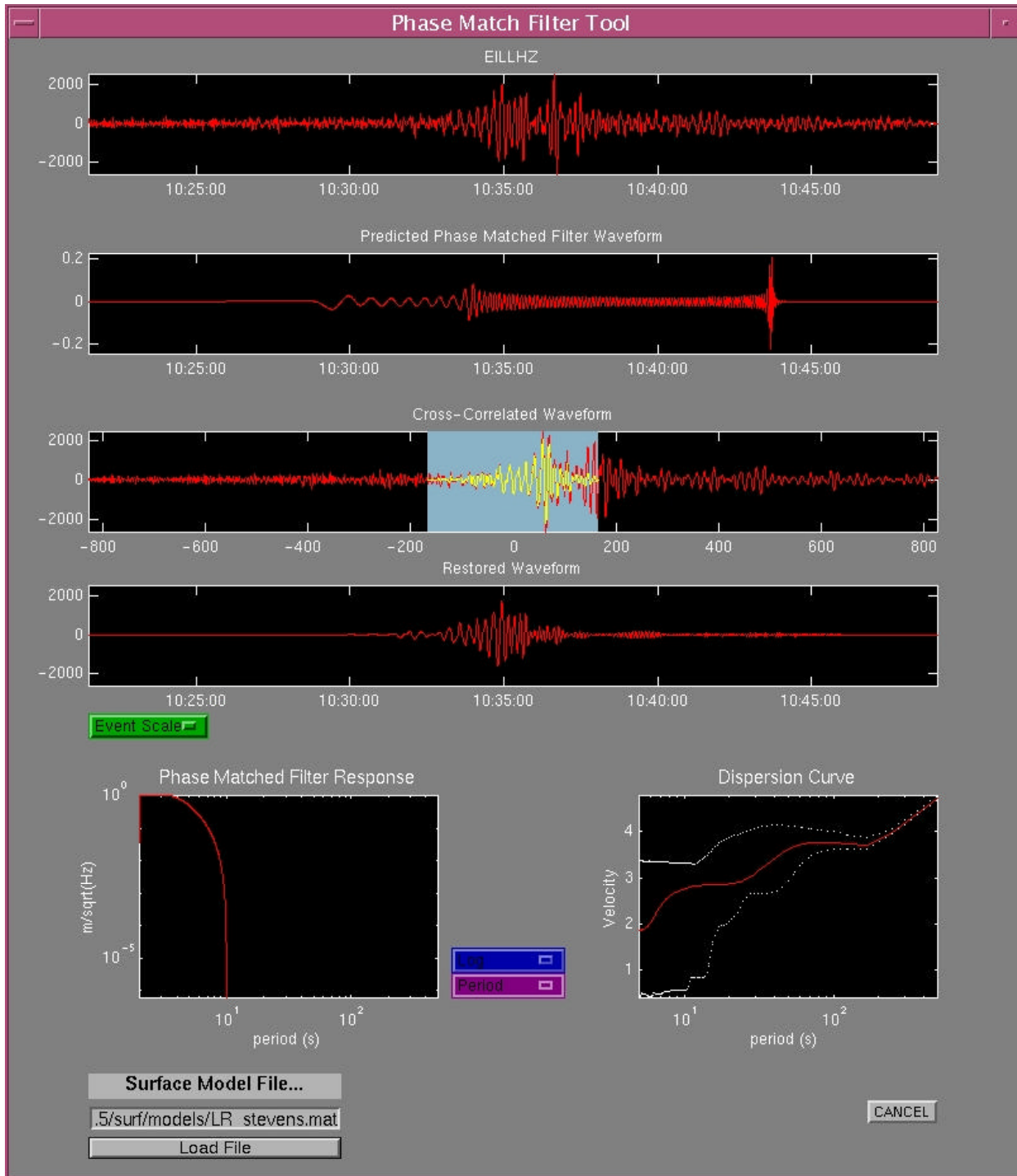
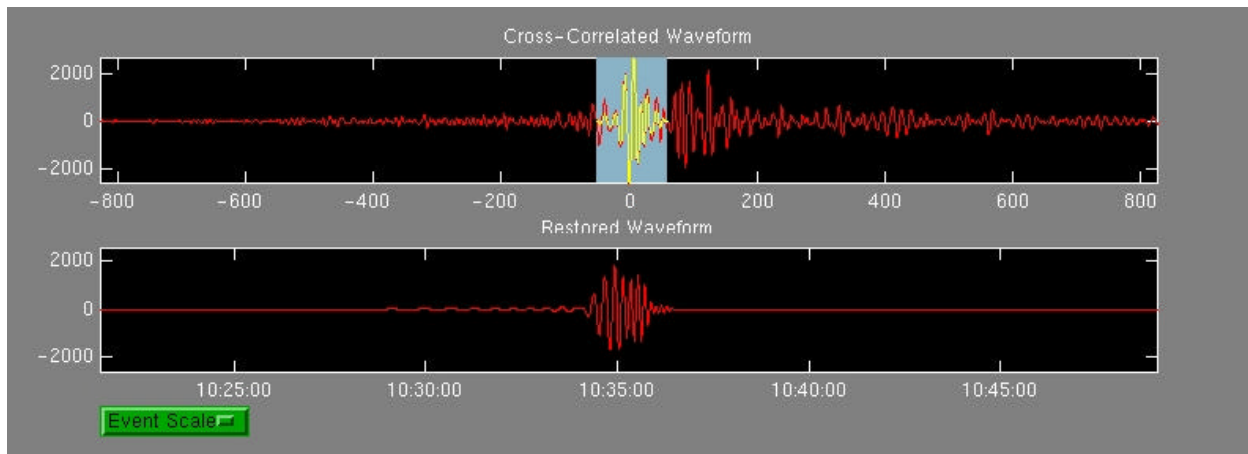
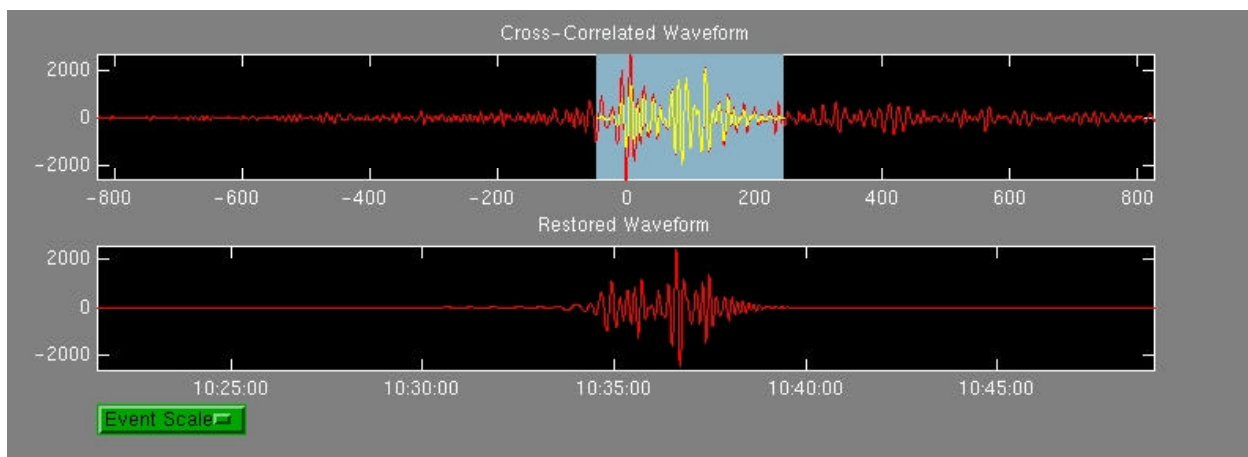


Figure 3. Phase Match Tool with ray traced path using Stevens Model.



**Figure 4. Restored Waveform for 100 sec window**



**Figure 5. Restored Waveform for 300 sec window**

The dispersion curve used to construct the phase-matched filter is shown in the bottom right corner of Figure 2. The dashed lines in the dispersion curve window indicate the maximum and minimum values among all cells in the model at each frequency. At this point, the dispersion curve and synthetic signal have been created. The phase-matched filter's frequency response spectrum is shown in the lower left corner window of the figure. The filter has an amplitude response of one across the frequencies tabulated in the model, and tapers to zero outside this band. The menu at the bottom of the interface allows the user to choose any available gridded dispersion model to test the effect of each on the performance of the matched filter. Figures 2 and 3 illustrate the results obtained using two different models with the same seismogram.

Figure 4 and Figure 5 demonstrate the effect of selecting different length segments of the correlogram. To restore the original Rayleigh arrival and eliminate extraneous noise, the highlighted segment is convolved with the phase-matched filter waveform to produce the restored waveform, shown at the bottom. As the selection box gets wider, the restored trace more closely resembles the original seismogram, but may reintroduce more noise or multipath energy.

## CONCLUSIONS AND RECOMMENDATIONS

We have implemented phase-matched filtering as MATLAB functions, and developed an easy-to-use graphical interface, which can be invoked from the MatSeis toolkit. As a result, a user can apply these techniques to any event in the database, and can select an appropriate Rayleigh propagation model. We will soon add the capability to measure amplitudes and periods from either the original or restored waveforms, then compute Ms magnitudes. Additionally, we plan to update the interface to allow the user to control the frequency response of the phase-matched filter.

## REFERENCES

Chael, E., M. Harris, C. Young, K. Mayeda, W. Walter, S. Taylor, A. Velasco, Prototyping regional discrimination tools with MatSeis, *Proceedings of the 21<sup>st</sup> Annual Seismic Research Symposium*, Sept. 1999, 294-299.

Harris, M. and C. Young, MatSeis: a seismic GUI and toolbox for MATLAB, *Seism. Res. Lett.*, **68**, 267-269, 1997.

Herrin, E. and T. Goforth, Phase-matched filters: application to the study of Rayleigh waves, *Bull. Seism. Soc. Am.*, **67**, 1259-1275, 1977.

Pasyanos, M. E., W. R. Walter and S. Hazler, Improving mb:Ms discrimination using phase matched filters derived from regional group velocity tomography, *Proceedings of the 21<sup>st</sup> Annual Seismic Research Symposium*, Sept. 1999, 565-571.

Pawlowicz, R., M\_Map: a mapping package for MATLAB, <http://www.ocgy.ubc.ca/~rich/map.html>, 1998.

Rezapour, M. and R. G. Pearce, Bias in surface-wave magnitude Ms due to inadequate distance corrections, *Bull. Seism. Soc. Am.*, **88**, 43-61, 1998.

Stevens, J. L. and D. A. Adams, Improved methods for regionalized surface wave analysis, *Proceedings of the 21<sup>st</sup> Annual Seismic Research Symposium*, Sept. 1999, 274-282.