# EVALUATION OF INTERMEDIATE-PERIOD (10- TO 30-SEC) RAYLEIGH-WAVE GROUP-VELOCITY MAPS FOR CENTRAL ASIA

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## ABSTRACT

We are evaluating the 10- to 30-second Rayleigh-wave group-velocity maps for central Asia constructed from maps developed by Levshin *et al.* (2001), Ritzwoller and Levshin (1998) and Stevens *et al.* (2001) for predicting surface-wave arrival times. Currently, we are focusing on the region between 15 and 55 degrees north latitude and 70 and 120 degrees east longitude. A new set of group-velocity measurements not included in the development of the tomographic maps has been used in the evaluation. The overall arrival-time predictions at all periods from the maps are good with the best predictions at 15 seconds. The group-velocity prediction-error (prediction minus measurement) distribution at 15 seconds has a mean of –0.0125 km/sec and a standard deviation of 0.095 km/sec.

We have tested the effectiveness of the maps in extracting surface-wave signals through phase-match filtering. Phase-matched filters constructed from the group-velocity maps seem to be effective in isolating and enhancing surface wave signals. In general, phase-matched filters have similar or better performance compared with bandpass filters in extracting surface-wave signals in the 17- to 23-second period range. Phase-matched filters could be particularly useful in situations in which multi-pathing is significant, surface waves from multiple events arrive close in time or there exists 20-second noise. Using the group-velocity maps also improved the number of surface-wave detections by 23% over a one-dimensional (1-D) model detection. It illustrates the usefulness of developing accurate group-velocity maps in lowering the surface-wave detection threshold.

We will begin testing the applicability of shorter period amplitude measures for estimating group-velocity maps down to 5 seconds. We also plan to broaden our study area to include regions further to the north.

## OBJECTIVE

The objective of this research is to develop methods for improvements to the regional $m_b$-$M_s$ discriminant. The research currently focuses on the evaluation and refinement of existing Rayleigh-wave group-velocity tomographic maps. These maps are used to construct phase-matched filters in an effort to reduce surface-wave detection thresholds and to construct regional $M_s$ scales. Our evaluation and refinement is part of the product integration process for US National Data Center monitoring operations.

## RESEARCH ACCOMPLISHED

### Study Region, Periods and the Group-Velocity Maps

Our current effort is focused on the central-Asia region between 15 and 55 degrees north latitude and between 70 and 120 degrees east longitude, and for periods between 10 and 30 seconds. There are a few group-velocity maps developed recently by different researchers that cover portions of the region and portions of the period range that we are studying. Ritzwoller and Levshin (1998) inverted group-velocity maps for the Eurasia continent that included our study area. The frequency range of their maps is from 20 to 200 seconds. Stevens *et al.* (2001) calculated global group-velocity maps for periods from 4 seconds up to 400 seconds from their global crust and upper-mantle structure model. Levshin *et al.* (2001) inverted a set of short- to intermediate-period (7 to 20 seconds) group-velocity measurements and obtained tomographic maps for the south Asia and east Africa region (10° ~ 50° N, 20° ~ 140° E). For the purpose of lowering surface-wave detection thresholds and developing regional $M_s$ scales, these shorter period maps are important.

To construct group-velocity maps for our region and for the periods between 10 and 30 seconds, we requested group-velocity maps from the above mentioned authors. Figure 1 illustrates the coverage of these maps except that of Stevens *et al.*'s (2001) maps (which are global,) and our study area. Restricted by the periods that these maps cover, we selected periods of 10, 11, 12, 13, 14, 15, 16, 18, 20, 25 and 30 seconds for our composite maps. We used

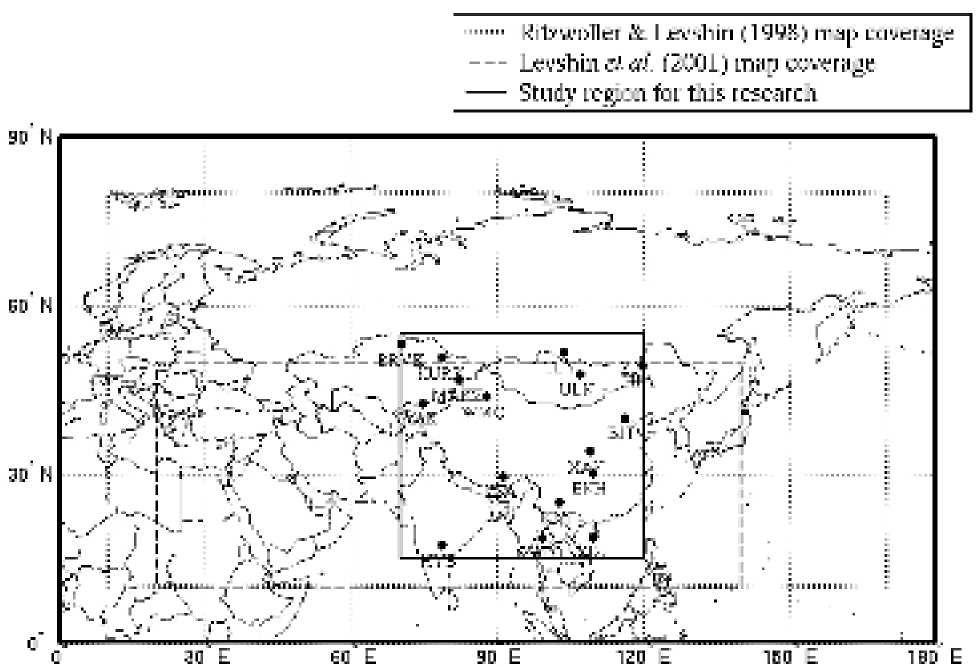


**Figure 1.** Geographic coverage of two of the group-velocity maps used in constructing the composite maps, and the study region. Data recorded at stations indicated in the figure were used in the analysis.

Levshin *et al.*'s (2001) maps for periods from 10 to 20 seconds and for the region south of 50° N in the composite maps. We used Stevens *et al.*'s (2001) maps for portions of the composite maps between 50° N and 55° N not covered by Levshin *et al.*'s (2001) maps from 10 to 18 seconds. For a 20-second map, we used Ritzwoller *et al.*'s (1998) map to fill in the area between 50° N and 55° N. We also used Ritzwoller *et al.*'s (1998) maps to construct the 25- and 30-second maps. The composite maps have a 1-degree spatial resolution. Figure 2 displays the 20-second composite group-velocity map for the study region. Major geographic features such as the Indian Subcontinent, the Himalaya Mountains, the Tarim Basin, the Junggar Basin, the Bay of Bengal and the South China

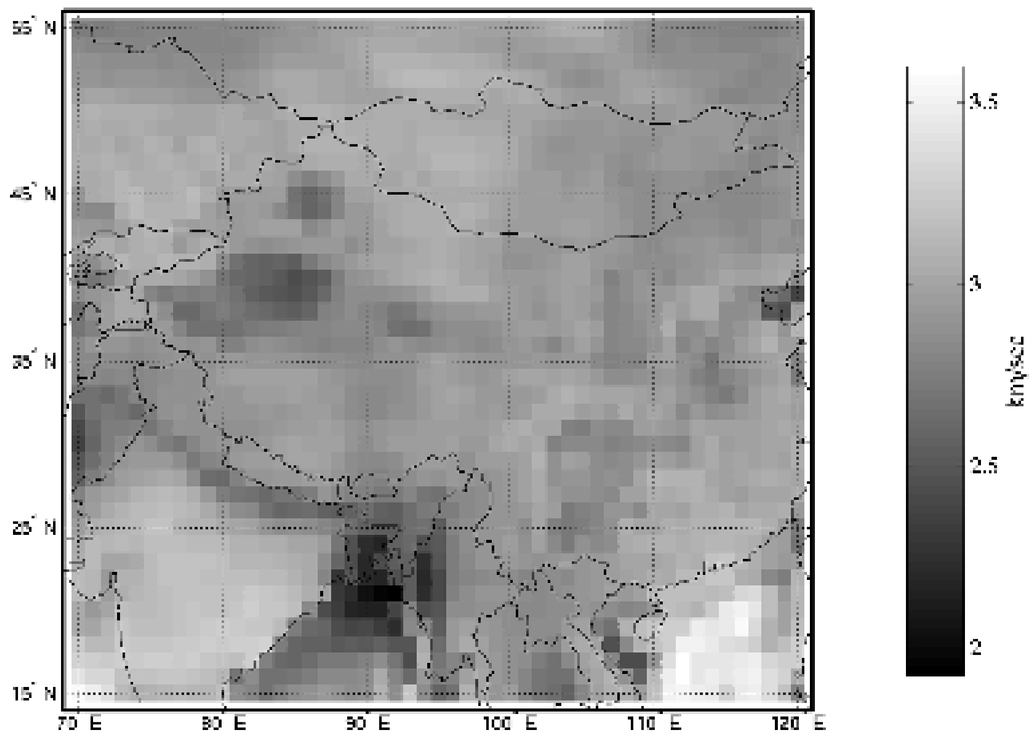


**Figure 2.** The composite, 20-second group-velocity map. The map has 1-degree resolution. Major geographic features are delineated by the variations of the group velocities.

Sea are characterized by deviations of surface-wave group velocities from the average. It suggests the consistency of the map with the tectonics of the region.

## <u>Group-Velocity Data</u>

In order to evaluate the group-velocity maps, we collected a set of vertical, broadband seismogram data recorded at stations shown in Figure 1 to make group-velocity measurements. These data are for events with magnitudes equal to or larger than 4 that occurred in 2001 in the study region. The data set was not used in inverting for the group-velocity maps that we intended to evaluate. Figure 3 shows the distribution of these events along with the stations that provided the data. Also shown is the path coverage of the 20-second group-velocity measurements. The numbers of the group-velocity measurements that we made from this data set range from 1403 to 1860 for different periods. The total number of measurements is 18755 for 293 events.

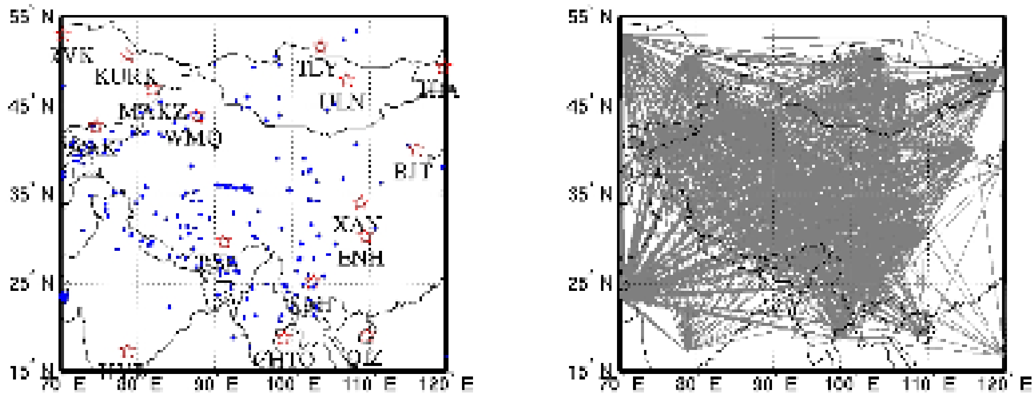


**Figure 3.** The event distribution for the data set that we collected (left) and the path distribution of 20-second group-velocity measurements that we made (right). The dots in the left plot are the events. The great-circle paths are shown as gray lines in the right plot.

## Group-Velocity Map Evaluation

We took several approaches to evaluate the performance of the group-velocity maps in predicting measured data. We calculated the differences between measured group velocities and predicted values and analyzed the residua distribution. We also constructed phase-matched filters from the group-velocity maps and applied the filters to surface-wave seismograms to see the effectiveness of the filters in enhancing the surface-wave signal-to-noise (S/N) ratio. Finally, we used Stevens and McLaughlin's (2001) surface-wave detection method and tested the improvement of the 2-D group-velocity maps in surface-wave detection over a 1-D China model (Jih, 1998).

### *Residua analysis*

Figure 4 plots the results of the residua analysis. Residua were obtained by subtracting the measurements from the predictions. They can be thought of as the prediction error with positive residua corresponding to faster group-velocity predictions. Plot b in the figure includes data for all periods. Analysis of data for individual period yielded similar distributions.

The overall map predictions are very good. Measured and predicted average group velocities follow each other closely. Most of the residua lie within the range between –0.5 and +0.5 km/sec. Their distribution is Gaussian-like with a mean close to zero. The standard deviations of the residua are in the similar range as those of the root-mean-square misfits of some surface-wave tomographic studies. For example, Ritzwoller and Levshin (1998) obtained a misfit of 0.09 km/sec for the 20-second Rayleigh wave. The misfit for 20-second Rayleigh wave was 0.127 km/sec in the surface-wave tomographic study of Pasyanos *et al.* (2001). The residua standard deviations of this analysis range from 0.095 to 0.138 km/sec with the minimum at 15 seconds. Whereas the map performance does not vary significantly across the period range of this analysis, best predictions occur near 15 seconds with the smallest residua standard deviations and smallest relative prediction errors.

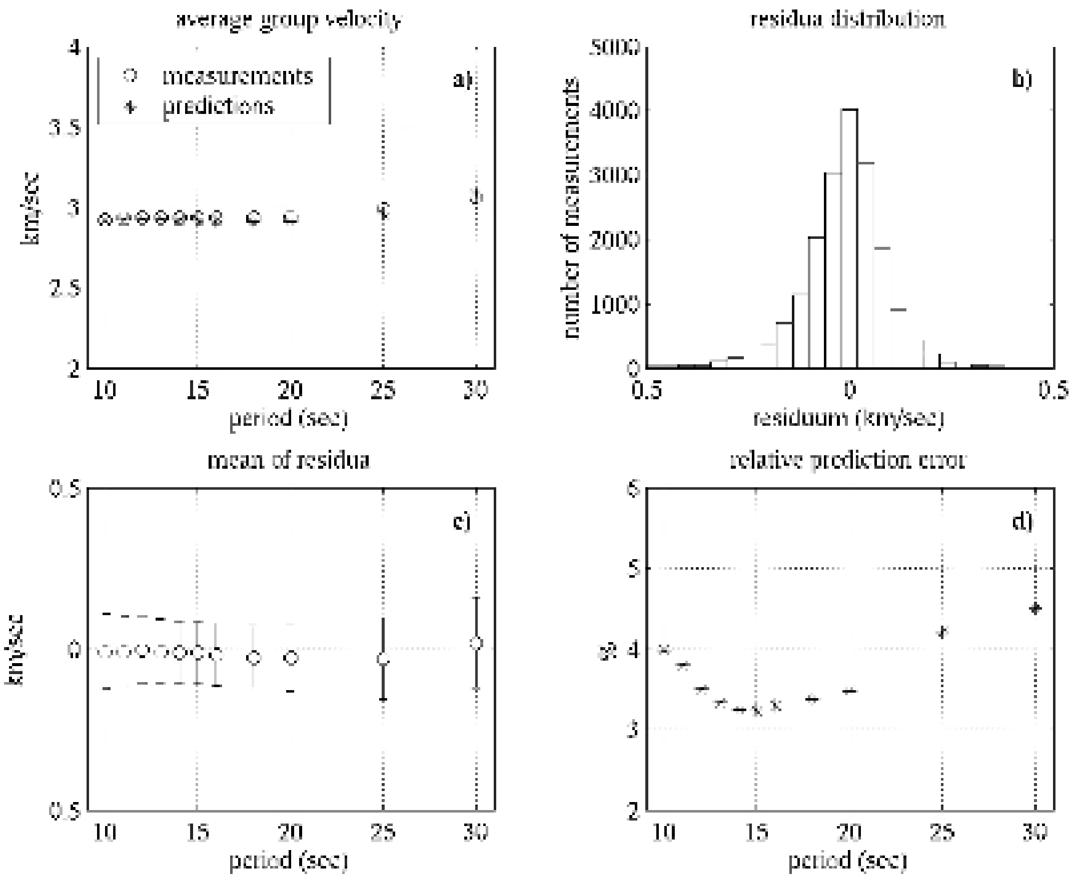


**Figure 4**. Residua analysis results. a) Average group velocities from the measurements and from the predictions. b) Distribution of residua obtained by subtracting the measurements from the predictions. Data for all periods are included. c) Mean of the residua as a function of period with one standard deviation of the residua as error bars. d) Relative prediction error obtained by dividing the residua standard deviation by the average measured group-velocities.

<u>*Phase-match filtering*</u>

Phase-matched filters (e.g., Herrin and Goforth, 1977) are used to enhance the S/N ratio of surface waves. The effectiveness of a phase-matched filter in extracting surface-wave signals depends on the accuracy of the group-velocities used to construct the filter. We constructed phase-matched filters with the group-velocity information from the maps and applied the filters to our data set. In general, the phase-matched filters are able to isolate the surface waves and suppress noise and other signals that do not arrive within the time window that the filters predict for the surface waves. Figure 5 gives such an example. If the event is well located, the group-velocity maps seem to be able to provide information accurate enough to construct an effective phase-matched filter.

In current practice, surface-wave magnitudes are calculated from amplitudes measured near 20 seconds. This is the reason that we focus our analysis around this period. One of the methods to improve the S/N ratio of a narrow-band surface-wave signal is to bandpass filter the data. We compared the methods of bandpass filtering and phase-match filtering by filtering both the original signal and the phase-match filtered signal between 17 and 23 seconds. For a large portion of the data tested, the two methods produced similar results to those shown in Figure 6. We did find situations where an additional phase-match filtering prior to bandpass filtering produced better results. An example is illustrated in Figure 7. We believe that phase-matched filters are useful particularly in situations in which multi-pathing is significant, surface waves from different events arrive close in time, or there is 20-second background noise in the data.

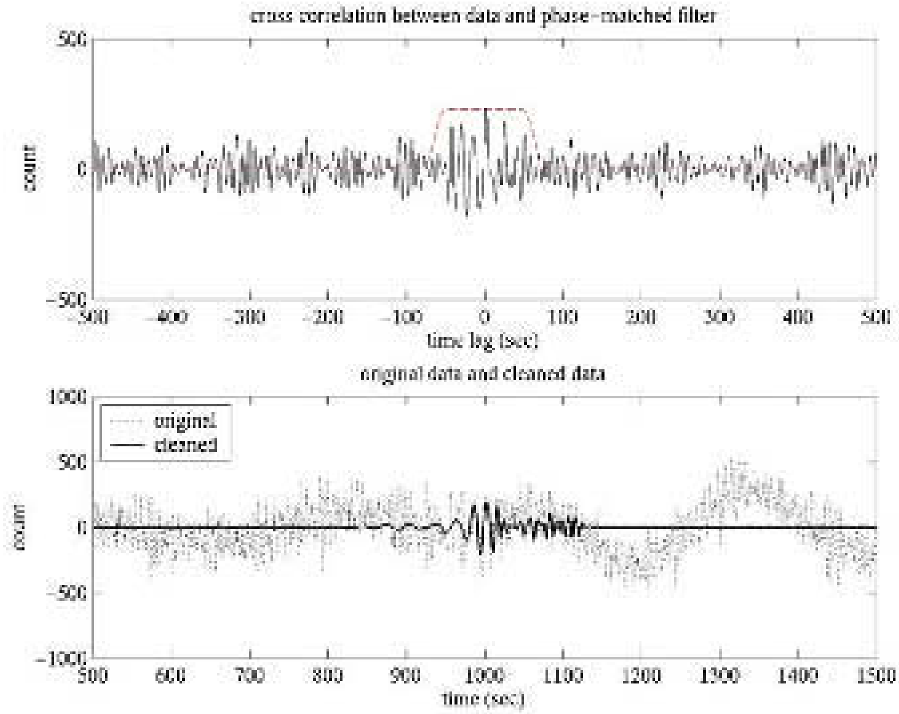


**Figure 5.** An example of phase-match filtering of the broadband data. The upper panel shows the cross-correlation between the data and the phase-matched filter constructed using group velocities from the maps. The event is an $m_b$ 4.8 event and the epicentral distance is 2788 km. The cross-correlation is windowed (dashed line) and convolved with the filter to obtain the cleaned data (lower panel). The effect of the phase-matched filter in extracting the surface wave is apparent.

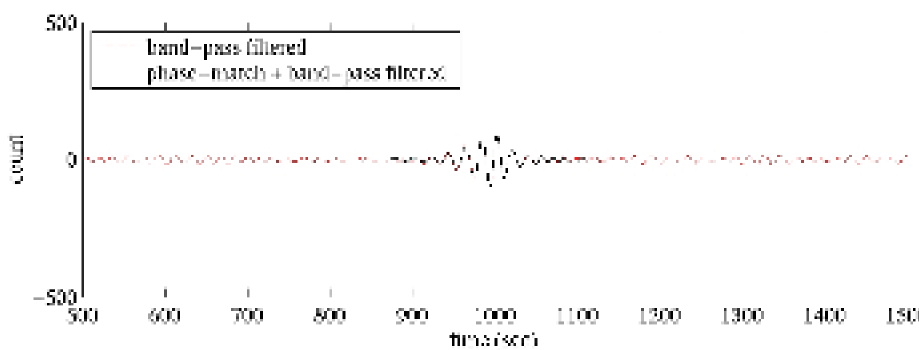


**Figure 6.** Comparison between the two filtering methods. Bandpass filter was applied to the data shown in the lower panel of Figure 5. In this case, simply bandpass filtering the broadband data has effects similar to phase-match plus band-pass filtering.

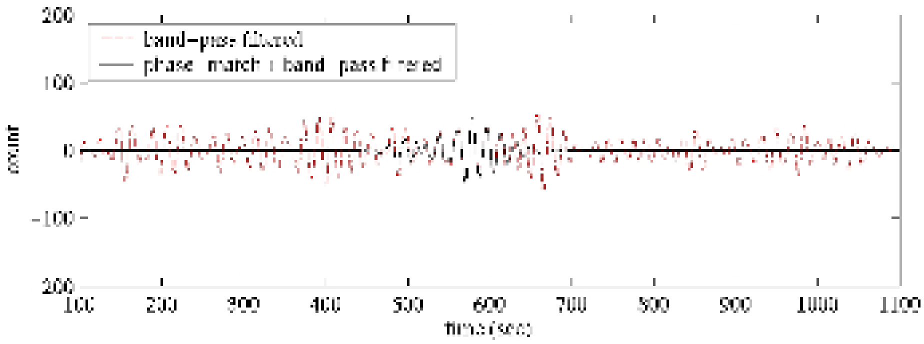

**Figure 7.** An example showing the difference between bandpass filtering method and phase-match plus bandpass filtering method. Due to the presence of 20-second noise resulting from a variety of possible sources, simple bandpass filtering cannot determine the surface wave unequivocally.

*Surface-wave detection*

Accurate group-velocity estimates can be used to improve the surface-wave detection. Stevens and McLaughlin (2001) described a method to detect surface waves with group-velocity information, which is used at the International Data Centre (IDC). The method uses multiple bandpass filters to filter the data and measures the arrival time of the peak amplitude at each period. If a certain percentage of the measurements fall within the range predicted by the group-velocity maps, the method declares a surface-wave detection.

We adopted Stevens and McLaughlin's (2001) method and tested the improvement of the group-velocity maps in detecting surface waves over some simplified 1-D models on our data set. In their practice, Stevens and McLaughlin (2001) made eight measurements within the period range between 17 and 50 seconds. To use our maps, we made measurements at each period between 10 and 30 seconds where we have a map. This period range covers shorter periods than Stevens and McLaughlin's (2001) period range. It should be more suitable for detecting smaller events at shorter epicentral distances. The equation used to define the arrival-time interval for a detection is (Stevens and McLaughlin, 2001):

$$\frac{r}{v_p + v_0} - p_0 T - t_0 < t < \frac{r}{v_p - v_0} + p_0 T + t_0 ,$$

where $r$ is the epicentral distance, $v_p$ is the predicted group velocity and $T$ is the period; $v_0$, $p_0$ and $t_0$ are constants that the user can use to adjust the width of the arrival-time interval. We set these constants to 0.2 km/sec, 1 and 0 sec, respectively. If 70% of the measurements fall within this interval, the detection is deemed successful. These parameters are the same as those used by Stevens and McLaughlin (2001).

Figure 8 plots the number of surface-wave detections using different group-velocity models. PREM and China are group-velocity predictions calculated from the PREM model and a 1-D China crustal model from Jih (1998). The use of group-velocity maps increased the number of detections by 23% over that with the China model.

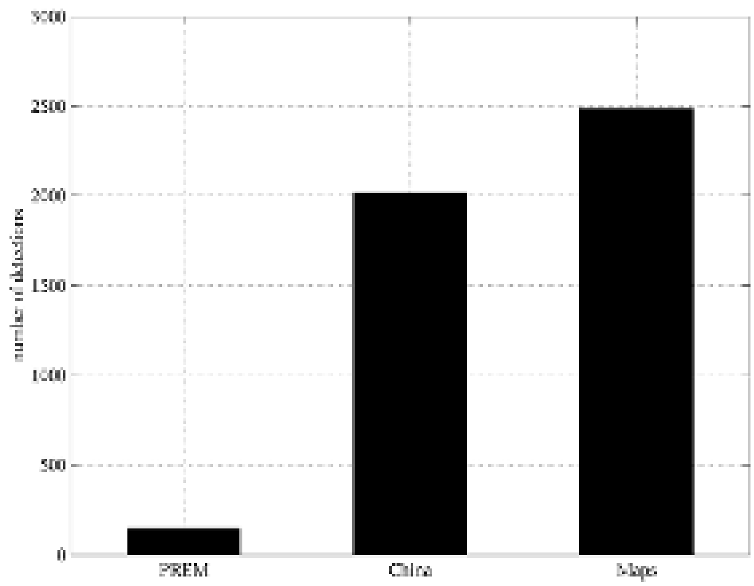


**Figure 8.** Number of surface-wave detections using different group-velocity models. PREM and China models are group-velocity predictions from the PREM earth model and a 1-D China crustal model (Jih, 1998). Maps are the composite group-velocity maps we evaluated.

## CONCLUSIONS AND RECOMMENDATIONS

We have evaluated Rayleigh-wave group-velocity maps for the central Asia region constructed from results of previous studies (Ritzwoller and Levshin, 1998; Stevens *et al.*, 2001; Levshin *et al.*, 2001). We collected vertical broadband data not used by these studies for the evaluation. We compared our group-velocity measurements with the map predictions. We tested the ability of the maps in constructing effective phase-matched filters. We also examined the improvement that the maps can achieve in surface-wave detection.

In all our tests, the maps performed well. Residua between the predictions and the measurements made on data not used in the inversion of the maps are of the same order as the misfits of data that were used in certain surface-wave inversions (Ritzwoller and Levshin, 1998; Pasyanos *et al.*, 2001). Phase-matched filters constructed from the group-velocity maps seem to be effective in isolating surface waves and enhancing the S/N ratio. Surface-wave detections are increased by 23% by replacing a 1-D model with the 2-D group-velocity maps.

In order to lower the $M_s$ detection threshold, surface waves with periods shorter than 20 seconds might need to be exploited. Enhancing the shorter period surface-wave signal requires accurate group-velocity maps at those periods. We are currently investigating the possibility of inverting for group-velocity maps down to 5 seconds at least for relatively small regions. We will make measurements at all periods below 200 seconds. New measurements at periods below 10 seconds can be used to improve the path density for certain regions that previous studies achieved. We also plan to broaden our region of evaluation to encompass the region further to the north. This will allow us to make use of new IMS stations in that region.

## ACKNOWLEDGEMENTS

We thank Anatoli Levshin of the University of Colorado at Boulder (CUB) for providing their group-velocity maps. The Eurasia maps were downloaded from the CUB web site. The global maps were downloaded from Maxwell's (now SAIC) web site. We appreciate Michael Ritzwoller and Jeffry Stevens' efforts in making these maps available.

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