Testing group velocity maps for Eurasia

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SUMMARY

Group velocity maps for seismic surface waves play an important role in monitoring the Comprehensive Test Ban Treaty so their accuracy is crucial. Group velocity anomalies can be modelled in terms of lateral variations in crustal and shallow mantle structure, the knowledge of which is important for understanding wave propagation and the blockage of regional phases. Accurate group velocity maps are also indispensable tools in attempts to lower the detection threshold for seismic events and to distinguish between explosions and earthquakes. This paper investigates the feasibility of validating existing maps using a relatively small data set of path-averaged group traveltime data. We find that group velocity correction surfaces calculated for two sets of global maps and a set of regional maps in Eurasia exhibit significant differences. We compare our measurements with predictions from these maps and test whether any of these maps is consistent with our data. Large differences between measurements and predictions can occur for selected individual paths across Eurasia and we find that maps resulting from global inversions fit our data best. There are visually only subtle differences between global and regional maps but we speculate that the long-wavelength structure is relatively poorly constrained in the regional maps.

Key words: Eurasia, group velocity, surface waves, surface wave correction surface, validation of seismic models.

1 INTRODUCTION

Observations of seismic surface waves provide very useful constraints on the structure of the Earth's crust and upper mantle. Various methods exist to analyse such data. While one type of method models the waveforms in terms of variations in depth-dependent structure directly (e.g., in the partitioned waveform inversion of Nolet 1990), others involve the measurement of dispersion which is then interpreted in terms of structure (e.g., Knopoff 1972). The dispersion of surface waves can be described by both frequency-dependent phase and group velocities where, in principle, measuring only one of the two parameters is necessary in order to determine the depth-dependent structure that is causing the dispersion. A great majority of the published papers describe the processing of phase measurements, while relatively few workers have chosen to measure group traveltimes. The latter group can be found especially within the Comprehensive Test Ban Treaty (CTBT) community. Measuring group traveltimes has certain advantages over measuring phase anomalies, the greatest being that one does not need to calculate synthetic seismograms that are necessary for accurate phase measurements. Group traveltimes are also typically less affected by source effects than phase anomalies. In fact, source effects can be ignored for most group traveltime measurements, though some exceptions exist (Levshin et al. 1999).

The group velocity of surface waves is typically more sensitive to shallow structure than phase velocity at the same period and group velocity data between 100 and 20 s provide excellent constraints on crustal structure. Having accurate information on variations in crustal structure at hand is essential for successfully monitoring a CTBT because such variations largely affect the propagation of regional phases and ultimately the event location process. Group velocity maps can also be used to calculate so-called group velocity correction surfaces (e.g., Levshin & Ritzwoller 2001). Such surfaces are widely used in phase-matched filtering routines to extract low signal-to-noise wave packets from a seismogram. Hence accurate group velocity maps can tremendously lower the detection threshold for small events. And yet, while global maps of surface wave phase velocity anomalies have been published on a regular basis (e.g., Trampert & Woodhouse 1995; Laske & Masters 1996; Ekström et al. 1997), and are widely used in global mantle tomographic studies (e.g., Gu & Dziewonski 1999; Masters et al. 2000), maps of group velocity anomalies are surprisingly rare in the literature. In fact, such maps have mostly been of regional scale (e.g., Ritzwoller & Levshin 1998 for Eurasia; Pasyanos 2000 for Northern Africa/Middle East) and global maps have not been available until very recently (e.g., Barmin et al. 2001; Larson & Ekström 2001).

In this study we compare group traveltime predictions from the newly available maps with our own measurements. We are
particularly interested in the question of whether the predictions are distinct enough, or our data precise enough, to help us decide which of the existing models is most consistent with our data. We should point out that our data set is far from being complete and is not comprehensive enough to make our own models. However, initial comparisons give us a valuable insight into obvious systematic differences between predictions and data. We regard our exercise as a validation of existing maps because our data are indeed independent: (1) our data were not used to make the maps; (2) the measurement techniques we apply use our own computer codes. It may be worthwhile to compare data sets of different workers (e.g. to identify systematic trends caused by one measurement technique or the other), but this is beyond the scope of this paper. We conclude this study by stressing the importance of embedding small-scale variations of regional structure in the appropriate global ‘long-wavelength’ context.

2 GROUP VELOCITY MAPS

Our study focuses on Eurasia, where nuclear tests are likely to occur and successfully monitoring the Comprehensive Test Ban Treaty is of particular interest. Accurate information on the 3-D seismic structure in this area is therefore essential. Starting with global group velocity maps, two sets of maps currently exist that can provide information concerning regional-scale variations in the area: one was derived by a group at Harvard University (Larson & Ekström 2001, LE maps hereafter) and the other by the group at the University of Colorado, Boulder, Levshin, Ritzwoller and Shapiro, personal communication; CUB hereafter). The LE maps were obtained by converting the phase measurements of Ekström et al. (1997) to group traveltimes and then inverting these for group velocity maps. The CUB maps were derived from measured group traveltimes, using the method of Barmin et al. (2001). A comparison of both sets of maps is particularly interesting because they are obviously obtained from different types of data. We also examine the regional group velocity maps of Ritzwoller & Levshin (1998) (RL hereafter). These cover the Eurasian continent between 10 and 170° E and between 10 and 80° N and are defined on a 1 x 1 deg2 grid, the finest parametrization used among the three sets of maps.

Fig. 1(a) shows Rayleigh wave maps at 90 s and Fig. 1(b) Love wave maps at 40 s. For each wave type, the global maps are very similar, displaying structure of similar wavelengths and roughly the same amplitude, while the regional map obviously contains higher-amplitude short-wavelength structure. Large differences between global and regional maps occur close to the edges of the regional maps, e.g. most of the Pacific Ocean and the Arctic Ocean north of Siberia. These differences are probably a result of the considerably poorer resolution in the regional maps at their edges that are constrained by only a few data (see also Ritzwoller & Levshin 1998). Despite the obvious similarity of the global maps, there are some disagreements, one being the slightly larger amplitudes in the CUB map. In the Rayleigh wave maps, there are also obvious differences in the Near-East. In the LE map, anomalies are smoothly varying (between 0 and −5 per cent), while they are rapidly varying in the CUB and RL maps (between −6 per cent in the Red Sea and 3 per cent east of the Persian Gulf). The gradients of structure from northern India toward the northeast across the Tibetan Plateau is also markedly different among the maps. It is somewhat surprising that the global Love wave maps appear to be more similar than the Rayleigh wave maps. Love wave measurements are typically more difficult to obtain, which should be reflected in differences between the maps of different workers. One hardly noticeable difference is located in the Mediterranean Sea, where the CUB map is slightly more negative.

As for Rayleigh waves, the regional Love wave map is quite different, the most obvious differences occurring in the Pacific Ocean and the Arctic Ocean north of Siberia. All three maps are remarkably similar in the Near-East, the only difference being a small-scale positive velocity anomaly immediately west of the Red Sea (−2 per cent for the LE map, −4 per cent for the CUB map but up to 8 per cent for the RL map).

3 DATA AND GROUP VELOCITY MEASUREMENTS

In this and the following sections, we try to evaluate how significant the differences between the group velocity maps really are and what impact these discrepancies have for a typical data set. For a comparison between predictions and data we assemble three data sets. One comprises the records of the temporary Saudi Arabian Seismic Network (SAUDI array hereafter) (Vernon et al. 1996), the second are selected records from the permanent Kyrgyz Network (KNET) (Mellors et al. 1997) and the third included records from seven broad-band stations of permanent global networks: PET, TATO and YAK (IRIS/USGS), ABKT, ERM and NRIL (IRIS/IDA) and HYB (Geoscope) (Fig. 2). The SAUDI array was operational between 1995 November and 1997 March and consisted of nine broad-band stations. As its data set we select 158 shallow events (depth <200 km) with scalar seismic moments between 0.5 × 1017 and 4 × 1020 N m. KNET is composed of 10 broad-band stations, with an aperture of approximately 200 km and interstation distances between 30 and 90 km. For this array we select the same events as for the SAUDI array.

We use a standard frequency–time analysis technique (FTAN) to measure the group velocity, a comprehensive treatment of which can be found in Levshin et al. (1989). A slight modification is based on the work of Shapiro & Singh (1999). For a particular measurement the chosen frequency is corrected for effects caused by the frequency dependence of the spectral amplitude. Group traveltimes are measured between earthquakes and stations assuming propagation along the source–receiver great-circle. As suggested by Levshin et al. (1999), we ignore the source group time, which is negligible compared with uncertainties in source location and origin time. In the frequency–time domain, we determine the envelope of the signal for each frequency. The amplitude maximum of the envelope is picked as the group traveltimes and the time window corresponding to 98 per cent of the amplitude peak is defined as an error bar. The traveltime is then converted to the path-averaged group velocity between the source and the receiver. The choice for the error bars sometimes results in a large scatter that may not reflect the actual precision of the measurement. For example, we obtain much larger error bars for long periods than for short periods, because the width of the time window is proportional to the period. Furthermore, for small epicentral distances the same traveltime error gives a larger group velocity error than for long epicentral distances. We therefore ‘equalize’ the errors by applying an empirical correction (new error [km s−1] = 0.1 × original error + 0.02), which effectively sets the maximum error at 0.1 km s−1.

We use data only in a certain epicentral distance range to avoid systematic outliers in our measurements. Only events with epicentral distances greater than 20° are considered. This reduces the bias in the measurements caused by neglecting source effects. Events with epicentral distances larger than 150° are also discarded because the bias introduced by multiplying effects may be significant.
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Figure 1. Group velocity maps used in this study: global map of Larson & Ekström (2001) on top, global map of Barmin et al. (2001) on middle and regional map of Ritzwoller & Levshin (1998) on bottom. Part (a) is for Rayleigh waves at 90 s and (b) is for Love waves at 40 s. The group velocities are expressed in perturbation with respect to the reference model anisotropic PREM anisotropic.

(Pavlis & Mahdi 1996). The source information is taken from the monthly preliminary determination of epicentres (PDE) provided by the NEIC. We note that this information can be quite different from the parameters published in the CMT catalogue (Dziewonski et al. 1981). We correct the group traveltimes adopting the ‘assumed source duration’ in the CMT catalogue, which results from the moment\(^{1/2}\) rule, but discard events for which the assumed duration is 25 s or longer.

4 COMPARING AVERAGE DISPERSION CURVES

We validate the existing group velocity maps by comparing their predictions with our measurements. Each of the predictions are determined by integrating the group traveltime along the source–receiver great-circle using the published maps. The resulting time is then converted to an apparent (or path-averaged) group velocity.
Figure 2. Broad-band stations used in this study: Saudi Arabian Seismic Network (bottom left-hand graph), installed from 1995 November to 1997 March, the permanent Kyrgyz array (top right-hand graph), and some permanent stations from global networks (Iris/Usgs, Iris/Ida and Geoscope).

Figure 3. Comparison between measured and predicted path-averaged group velocities for data collected at the Saudi array, both for Rayleigh (a and c) and Love (b and d) waves. Results are obtained for our ‘global data set’ and for our ‘regional data set’. Triangles represent our measurements (see text for the details on error bars) and the solid line is the anisotropic PREM model. Calculations were performed using the RL map (long dashed line), the LE one (intermediate dashed line) and the CUB one (short dashed line).

Fig. 3 shows the mean dispersion curves that are obtained by averaging all dispersion curves in our SAUDI data set. Also shown are their ‘statistical error bars’. We prefer to work with the statistical errors instead of the original measurement errors because we regard them as being more representative of the actual scatter of data within the SAUDI array. As mentioned above, the measurement technique yields errors that are proportional to the period. We notice, however, that at long periods the variation in group velocity between stations...
is much less than the measurement errors would suggest. We infer from this that the group velocity can be measured more accurately than what is given by the measurement technique. We therefore derive a ‘statistical error’ which is the frequency-dependent average over the standard deviations of all events. The latter is simply the formal standard deviation of the measurements of a specific event and can be determined if more than one station recorded this event. In some cases this error is actually smaller at long periods than at short periods. The most likely explanation for this is that strongly heterogeneous shallow local structure causes a larger variance in the measurements at short periods than at long periods.

We perform a comparison for two cases. In the first one, we average over all available measurements (global data set), while in the second case, we only consider paths corresponding to sources that lie within the regional map (regional data set). We first notice a significant difference between the average dispersion curves of the ‘global data set’ and the ‘regional data set’. This is especially the case for periods shorter than 70 s for which the ‘global’ group velocities are higher than the ‘regional’ ones. The reason for this is that the ‘regional data set’ does not contain any measurements that include the oceanic paths that are typically faster for periods between 60 and 17 s. Also shown in Fig. 3 are the means of the predicted group velocities. There is a marginal but probably significant difference between the predicted curves using the global maps on one hand and the regional maps on the other hand. A possible discrepancy at long periods may be caused by the fact that the regional maps were made using a flat-Earth approximation (Levshin, personal communication) which we ignored when calculating the predictions. This becomes increasingly relevant for velocities of deeper structure, for which the velocities in the flat Earth are larger than in the spherical Earth, changing the surface wave dispersion at long periods accordingly. Ignoring the flat-Earth transformation would not explain, however, the good agreement between the regional maps and the global maps. This is especially the case for periods longer than 90 s.

When comparing the observed dispersion curves for Rayleigh waves with the predicted ones, we find differences that are all smaller than 0.025 km s\(^{-1}\) (0.7 per cent). This is within the error bars, except for the RL maps for periods shorter than 35 s. The predictions of the two global maps are closer than 0.7 per cent for the ‘global data set’ and closer than 1.0 per cent for the ‘regional data set’. The predictions of the CUB maps fit our measurements extremely well at periods shorter than 60 s, but at longer periods our measurements tend towards the lower velocities predicted by the LE maps. At periods longer than 125 s, our data become increasingly inconsistent with the CUB maps (and with the RL maps). The reason for this is not entirely understood, especially since there is no noticeable difference between the observed ‘regional’ and ‘global’ dispersion curves at these periods. This suggests that the CUB and the RL maps contain a large-scale ‘fast’ component that is absent in the LE maps and also not required by our data. We notice that at long periods, the slow regions around the Tibetan Plateau are typically somewhat larger and slower in the LE maps than in the other maps, possibly causing the baseline shift in the mean dispersion curves seen in Fig. 3.

The observed average Love wave dispersion curves are not as smooth as those for Rayleigh waves. There are typically only half as many data for this wave type (Tables 1 and 2) and the individual data are noisier. The number of available ray paths also changes significantly with period. A certain ‘roughness’ of the curves for the predictions reflects the uneven averaging occurring over different seismic structure. This is especially the case for periods shorter than 40 s where all ray paths lie within the regional map and a ‘global data set’ does not really exist. There is an excellent agreement, however, between predictions of different maps, for periods shorter than roughly 70 s. This agreement may also be inferred from the great similarity of the maps shown in Fig. 1(b). Note, however, that the differences between measurements and predictions are greater than for Rayleigh waves and can reach 3.1 per cent, which is probably a result of the higher noise level in the Love wave data set.

In order to quantify the discrepancies found in Fig. 3, we compare the variance reductions obtained for our measurements using the published maps (Tables 1 and 2). The variance reduction generally increases with decreasing period but is very similar for different models, at fixed period. Exception are at long periods (90 s and beyond) for which the LE maps give a significantly better fit to the data than the other maps. Variance reductions for all maps are especially high for periods shorter than 60 s for Rayleigh waves, for both global and regional data sets. For Love waves, variance reductions are highest for periods between 50 and 30 s for the ‘global
Figure 4. Group velocity correction surfaces for Rayleigh wave at 40 s. For all fictitious sources located on a grid we calculate path-averaged group velocities for each source-station path. These values are computed for ‘reference station’ AFIF, HYB, ERM and AAK from top to bottom. The grey-scale in m s\(^{-1}\) gives the results relative to reference model anisotropic PREM. The left-hand column is for the RL map, the middle column for the CUB map and the right-hand column for the LE map.

data set’, and between 80 and 30 s for the ‘regional data set’. Again, our observations seem to be best fitted by the LE maps at the longest periods beyond 100 s.

5 GROUP VELOCITY CORRECTION SURFACES

A useful tool to identify source regions for which the largest discrepancies in the predictions of different models are to be expected are so-called group velocity correction surfaces (GVCS). For a given group velocity map, such correction surfaces are calculated for each individual seismic station. For a given station, we compute the path-averaged group velocities for all fictitious sources on a grid within Eurasia. The calculated values are then plotted at the fictitious source locations. Fig. 4 shows the resulting GVCSs for Rayleigh waves at 90 s for stations AFIF (SAUDI), HYB (Geoscope), ERM and AAK (IRIS/IDA). For each of these stations, the largest differences between GVCSs for different group velocity maps are found close to the edges of the diagrams (e.g. for AFIF in the northeast or ERM in
the Pacific Ocean). These differences are most pronounced when significant fractions of the ray paths are along the poorly resolved edges of the RL maps. For station AFIF, differences between the three GVCSs also occur in the Near- and Middle-East, where anomalies are more negative for the LE surface, and East of China and Japan, where the LE surface is smooth while the RL and CUB surfaces reveal significant changes from south to north. For station HYB, the LE surface has negative anomalies in Africa while the two other GVCSs have positive anomalies. For events in the Kuril Islands, the LE surface also reveals stronger negative anomalies than the other ones. The correction surfaces for station ERM are dominated by large-scale strongly negative anomalies, which are again strongest for the LE surface. The negative anomalies for events in Siberia are shifted toward the west in the RL surface compared with the GVCSs for the two global maps. Perhaps the group velocities between sources in this region and station ERM are less well resolved in the regional map. Note that values in this area are associated with rather short travel paths that have not yet undergone significant path-averaging effects. Hence, relatively small differences in the group velocity maps would manifest themselves as relatively large differences in the correction surfaces. The correction surfaces for station AAK are very similar with only small differences in the magnitude of the anomalies (<10–20 m s⁻¹). It may therefore be difficult to validate group velocity maps for Rayleigh waves at 40 s for Eurasia, especially the western and northern areas, using data from station AAK alone.

We would expect that discrepancies in published models should occur on small scales, because different data sets (and modelling techniques) used by different workers should differ in detail but not on average (or large scales). Consequently, the group velocity correction surfaces should differ on small scales and the predictions for individual paths should probably scatter but exhibit no obvious systematic behaviour. We expect a particularly large scatter at short periods for which Rayleigh waves are most sensitive to crustal structure, which is particularly complex around the Tibetan Plateau. Yet, for Rayleigh waves at 40 s, the main differences between group velocity maps (as well as between the corresponding areas in the correction surfaces) do not occur in this area (not shown). We note a long-wavelength component in the LE map that makes the group velocity correction surfaces more negative than those for the RL and CUB maps over a large area. This discrepancy supports the systematic shifts we found in Fig. 3, where the curves for the LE maps were systematically lower than those for the RL and CUB maps.

6 ANALYSING INDIVIDUAL TRAVEL PATHS

The comparison of group velocity correction surfaces for different group velocity maps has shown that significant discrepancies exist in the path-averaged group velocities for some source-receiver pairs. We now select individual paths within Eurasia and compare our measurements with the predictions from the three different sets of maps. Fig. 5 summarizes the selection of paths and Figs 6 and 7 compare our observed dispersion curves with predicted ones. We plot the dispersion curves as well as the percentage differences between the curves. For the two network data sets, SAUDI and KNET, we average the dispersion data for a given event over all stations. The resulting curve should give the average dispersion between an event and the networks. A slight scatter at fixed frequency is caused by the slightly different structure sensed along slightly different ray paths and differently sampled near-receiver structure. Figs 6(a) and 7(a) show observations and predictions for the SAUDI array. For the source located to the southeast of Tibet (no 1), the predictions for the regional maps fit our measurements very well over the whole period range (20–175 s). The global CUB maps fit our measurements only for periods longer than 60 s but underpredict them for shorter periods, while the global LE maps underpredict our measurements for periods shorter than 150 s, and differences can reach 6.0 per cent (e.g. for 35 s). For both sources in the Philippines (events nos 2 and 4), the RL maps slightly overpredict our measurements for periods shorter than 70 s. For both events, the LE maps underpredict the data over almost the whole period range, though the discrepancy is more obvious for event no 4. The CUB maps give the best fit to our data for both events, though there is some discrepancy at longer periods for event no 4. The events were relatively close so the measurements should agree. We speculate that possible overtone contamination at longer periods for event no 4 causes the relatively small difference. This example stresses, however, that a detailed validation process of models is only meaningful when using a comprehensive data set (i.e. different paths, repeat measurements for similar paths). For the two sources in Japan and northwest of Tibet (events nos 3 and 5), for which parts of the travel paths to the SAUDI array overlap, the measurements scatter significantly and are more difficult to interpret. In particular, reliable estimates for event no 5 are only possible for periods shorter than 70 s. In general, the two sets of global maps fit our data better, while again the regional maps slightly overpredict our data. The data from KNET (Figs 6b and 7b) exhibit a significant scatter, the cause of which is not entirely clear. We notice that the waveforms are generally much more coherent across the SAUDI array than across KNET despite the significantly wider station spacing. The frequency-dependent oscillations in individual dispersion curves (such as for event no 4 in Fig. 6b) are unphysical and reflect uncertainties for individual estimates. Such sections of the dispersion curve are not considered in the validation of a model. We suspect that strong lateral heterogeneity in the area around the Tibetan Plateau causes severe propagation effects (see e.g. Pavlis & Mahdi 1996) and hence affects our measurements. Note, however, that existing maps clearly seem to overpredict measurements for which paths cross the Tibetan Plateau (i.e. event no 1).

We conclude this comparison by presenting results for a few permanent global seismic network (GSN) stations. For stations ABKT, HYB, and TATO, we choose an event located in the Adriatic Sea (events nos 1 in Fig. 5c). Both sets of global maps fit our measurements very well, while the regional RL maps overpredict our data for PET (at periods shorter than 90 s) and to some extent for YAK. In some cases the discrepancy can reach 4 per cent, which is much larger than our most pessimistic error bars, and hence significant. For station ABKT, we choose three events located along the Pacific Rim, one in Northern Japan (no 2), one in the Philippines (no 3) and one in the Kuril Islands region (no 4). The three paths are very different (see Fig. 5c) so not surprisingly, the measured path-averaged group velocities are also rather different. For the two northern paths (events nos 2 and 4), differences between predictions as well as between predictions and measurements are exceptionally small, the only discrepancy being that the RL maps sometimes slightly overpredict the measurements. The LE maps slightly underpredict our long-period data for event no 4. For the source in the Philippines (event no 3), the differences are greater, and although the measurements are somewhat oscillatory, we can identify the CUB maps as the set of maps being most consistent with our data. Both sets of global maps are consistent with our measurements at station ERM (Figs 6d and 7d) and the regional RL maps overpredict them. For stations ABKT and HYB, our measurements are clearly inconsistent with the RL maps.
Both paths TATO-event no 3 and HYB-event no 6 lie along the edge of the regional map so this discrepancy is not too surprising. The case HYB-event no 5 is less obvious, however, and the LE global maps give the best fit to our data. Finally, the large scatter in the dispersion curves for NRIL does not allow a conclusive comparison. In summary, we find that the set of global maps fits our data best and may be the most appropriate to represent effects on the Rayleigh wave group velocity caused by variations in crustal and upper mantle structure in Eurasia.

### 7 Summary and Discussion

The success of the seismic monitoring of a Comprehensive Test Ban Treaty depends largely on the quality of the structural models seismologists use to predict their data. In this study we present an attempt at validating some existing models for Eurasia using surface waves. We measure path-averaged group velocities using data from the Saudi Arabian Seismic Network, the Kyrgyz Network and from selected stations of the permanent global seismic networks. In our validation tests we compare these data with predictions using three sets of available group velocity maps. These maps are intrinsically rather different so a comparison is particularly interesting. On one hand, we have the opportunity to test predictions that ultimately came from very different data sets: one set of group velocity maps were constructed from group traveltime data and another one from phase data. We are also able to test how well global maps fare relative to more regional-scale maps, using regional-scale data sets. The regional maps provide the finest parametrization and display the largest amount of small-scale features. We therefore anticipated that the most obvious discrepancies between data and predictions as well as between predictions of different maps would occur for relatively short travel paths when path-averaging effects have not yet diminished the effects of small-scale structure below a detectable limit. Yet the group velocity correction surfaces for the regional Ritzwoller & Levshin (1998) maps and their global maps (CUB), which were made from group traveltimes and include the same regional data set, are generally astonishingly similar. Some exceptions exist and the regional maps indeed exhibit much larger anomalies for certain source locations. The group velocity correction surfaces for the global maps of Larson & Ekström (2001) (LE), that came from phase data, are rather smooth. It is intriguing that these correction surfaces also appear shifted systematically towards lower path-averaged group velocities.

We find large systematic discrepancies between our data and the regional maps, which often overpredict our measurements, especially at short periods, sometimes by as much as 3 per cent. We take
this as being indicative of a significant lack of large-scale structure in these maps. The differences between predictions from the two global maps are usually small, rarely exceeding 3.0 per cent, but differences between regional and global maps are usually larger and can reach 3.8 per cent. The global maps usually provide a good fit to our data where the CUB maps appear most consistent with measurements of selected travel paths. This is particularly the case for periods shorter than 70 s for which our measurement errors are small. On average, however, these maps seem to have a systematic offset toward high velocities with respect to our data, especially at long periods (Fig. 3) though discrepancies lie just within our error bars. The global LE maps are in excellent agreement with our average dispersion curves at periods above 45 s. These results are somewhat puzzling as we expect these maps to be least consistent with our data. We are left to conclude that the CUB maps are the best models to describe short-period Rayleigh wave group
velocities within Eurasia. For the purpose of using the CUB maps in the monitoring of a CTBT, however, we recommend an adjustment to the long-wavelength component at longer periods.

Our observations stimulate us to participate in the discussion on the compatibility of regional and global models. Chevrot et al. (1998a,b) find no obvious gap between the power spectral density of global and regional Love wave phase velocity maps in a region covering the Tibetan Plateau. On the other hand, there appears to be considerable disagreement between the spectra of certain global shear velocity models (Zhang & Tanimoto 1993; Ekström & Dziewonski 1998) and the regional model of the Australian continent by Zielhuis & van der Hilst (1996), at wavelengths where the models overlap. Although we do not further quantify our comparison, we find that in our study the regional group velocity maps also have long-wavelength spectral amplitudes that are different from those of the global maps. We speculate that these gaps between global and regional models can occur because the bulk of the data used for regional modelling have significantly shorter travel paths than those for global models. Such data are intrinsically less sensitive to long-wavelength structure so the resulting model errors are larger. To estimate possible trade-offs in global and regional models, we perform a test using synthetic data. We take a map similar to the phase velocity map of Laske & Masters (1996) at 10 mHz that is
significantly amounts of short-wavelength structure, up to spherical harmonic degree 36 (Fig. 8a). We calculate 6000 synthetic R1, R2 and great-circle data for this map (global data set). A second data set of 1500 data (regional data set) is constructed that includes only paths with sources and receivers that lie within a box with boundaries 10°–170° in longitude and 0°–80° in latitude. The median of the length of travel paths is 46° in the regional data set and 85° for the global R1 data so the regional data set is expected to be less sensitive to long-wavelength structure. We perform two inversions for equal area block maps (the block size at the equator is 5°), one for a global map using the global data set and one for a regional map using the regional data set. The maps are obtained with the iterative LSQR technique of Masters et al. (2000). The input and output maps are virtually identical (not shown) and both output maps fit their respective data sets. The amplitude spectra of the spherical harmonic expansions of the input and output maps, considering only values within the regional box, are shown in Fig. 8(b). The spectra of the input map and the ‘global map’ agree well at wavelengths longer than 2500 km but there is considerable disagreement between the input and the ‘regional’ map. The average values of phase velocity perturbation in the regional box are −0.27 per cent (input), −0.32 per cent (global) and 0.52 per cent (regional). The regional map is therefore obviously composed of long-wavelength structure that is significantly different from both the input and ‘global’ output maps. Such a map can potentially mispredict the averages of data sets with long travel paths, similar to the cases we have shown in this study. Of course, when combing the data sets in a third inversion the resulting output map is much closer to the input map (not shown). We speculate that a combination of global and regional data can greatly diminish the problems we have described, especially when using a variable parametrization to accommodate the strongly varying resolution capabilities of the data (e.g. Boschi & Ekström 2000).

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Figure 8. (a) Eurasian section of the global input map of the synthetic experiment. The map is a rough version of the Rayleigh wave phase velocity map of Laske & Masters (1996) at 10 mHz. Anomalies are given as percentage velocity perturbations with respect to a spherical average. (b) Amplitude spectra of the Eurasian section of the input and output maps. The spectra are obtained by expanding the maps in surface spherical harmonics considering only values within the regional section shown in Fig. 8(a). The amplitudes are normalized so that the spectrum of a spike would be flat.
REFERENCES


