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The Influence of Deep Sedimentary Basins, Crustal Thining, Attenuation, and Topography on Regional Phases: Selected Examples from the Eastern Mediteranean and the Caspian Sea Regions

P. Goldstein, C. Schultz, S. Larsen

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The Influence Of Deep Sedimentary Basins, Crustal Thining, Attenuation, And Topography On Regional Phases: Selected Examples From the Eastern Mediteranean and the Caspian Sea Regions

Peter Goldstein, Craig Schultz, and Shawn Larsen
Geophysics and Global Security Division, Lawrence Livermore National Laboratory

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Monitoring of a CTBT will require transportable seismic identification techniques, especially in regions where there is limited data. Unfortunately, most existing techniques are empirical and can not be used reliably in new regions. Our goal is to help develop transportable regional identification techniques by improving our ability to predict the behavior of regional phases and discriminants in diverse geologic regions and in regions with little or no data. Our approach is to use numerical modeling to understand the physical basis for regional wave propagation phenomena and to use this understanding to help explain observed behavior of regional phases and discriminants. In this paper, we focus on results from simulations of data in selected regions and investigate the sensitivity of these regional simulations to various features of the crustal structure. Our initial models use teleseismically estimated source locations, mechanisms, and durations and seismological structures that have been determined by others. We model the Mb 5.9, October 1992, Cairo Egypt earthquake at a station at Ankara Turkey (ANTO) using a two-dimensional crustal model consisting of a water layer over a deep sedimentary basin with a thinning crust beneath the basin. Despite the complex tectonics of the Eastern Mediteranean region, we find suprisingly good agreement between the observed data and synthetics based on this relatively smooth two-dimensional model.

We investigated the sensitivity of the Cairo earthquake synthetics to a number of features including: 1) the thickness and velocity of the sedimentary basin, 2) the amount of crustal thinning beneath the basin, 3) the amount of attenuation, and 4) The presence of a water layer. We find that, for this region, the presence of a thick sedimentary basin has the most dramatic effects on the regional phases. For example, Pg and Sn are effectively extinguished and the surface waves are dramatically dispersed by the presence of the basin. Crustal thining beneath the basin also reduces the amplitudes of Pg and Sn, but its effects are less significant. The effects of attenuation are well approximated by a low-pass filter. The effects of the water layer were small but most noticeable in the later arriving surface waves.

We investigated the effects of free-surface topography for paths in the vicinity of the Caspian Sea. Preliminary results indicate that topography acts as a significant source of scattering and mode conversion. One of the most noticeable effects was a significant increase in the duration of Lg on the vertical component. This result suggests that free-surface topography may be an important contributor to the development of Lg and coda waves. It may also explain the relatively homogeneous nature of three-component regional waveforms.

These result show how we can use simulations to understand observed regional wave propagation phenomena and suggest that it may be possible to predict the behavior of regional phases and discriminants when we have a reasonably accurate model for the regional seismic structure.

Key Words: Seismic, Wave Propagation Modeling, Identification, Regionalization, Middel East, Caspian, Topography

Objectives

We have been developing the capabilities needed to model regional seismic signals in complex media (e.g., Larsen, 1995; Schultz et al., 1995; Goldstein, et al., 1996; Schultz, 1997) so that we can help understand the physical basis for and performance of existing discriminants, develop transportable seismic identification techniques, and predict the behavior of regional phases and discriminants in regions where there is limited data. In this study, we investigate the sensitivity of regional phases in complex media to features such as deep sedimentary basins, crustal thinning, attenuation, and free-surface topography. Our goal is to understand how these features affect regional signals and to identify those features that have the greatest impact from a monitoring standpoint.

Research Accomplished

Software Development

Our effort to model the propagation of regional phases in complex media to distances and frequencies of monitoring interest has required significant development of our finite-difference wave propagation modeling capabilities (Larsen, 1995). Important enhancements include: hybridization (the ability to input signals from other seismic modeling techniques), two-dimensional topography (Schultz, 1997), and a number of techniques to improve computational speed and efficiency. This software development and the increased speed and efficiency of available computers has brought us to the point where we will can begin to model regional phases in realistic structures and at frequencies and distances of monitoring interest.

The October, 1992 Cairo, Egypt Earthquake

We simulated the October 1992, Cairo Egypt earthquake, Figure 1, in order to test our predictive modeling capabilities and to investigate the sensitivity of regional phases to complex regional structure. We began by simulating recordings of this earthquake at Ankara, Turkey (ANTO) using the location determined by the National Earthquake Information Center and the Centroid Moment Tensor (CMT) mechanism and source duration (Dziewonski et al., 1981). Based on the depth to basement and crustal thickness given in Cornell University Digital Database for the Middle East and North Africa (Barazangi et al., 1996), we used a two-dimensional earth structure consisting of three crustal layers , the Mediteranean Sea, a thick sedimentary basin, and deeper crust that thins beneath the sedimenatary basin (Figure 2). The upper mantle consists of a uniform velocity gradient extending to a depth of 100 km. This structure is deep enough to model Pn and Sn but will not include the effects of any upper mantle discontinuities. In Figure 3, we compare the observed data with the simulation based on the model in Figure 2 and a flat layered approximation of this model. We find excellent agreement between the observed data and the synthetic generated using the two-dimensional structure. In contrast, there are dramatic differencces between the flat layered approximation and the observed data. The excellent agreement between observed data and synthetic based on the two-dimensional model suggest that it may be possible to predict regional waveforms in regions where we have reasonably accurate estimates of the seismic velocity structure.

Sensitivity of regional phases to two-dimensional crustal structures:

In this section, we describe our investigation of the sensitivity of our simulations of the Cairo, Egypt earthquake to a number of features of the two-dimensional crustal model including: 1) the thickness and velocity of the sedimentary basin, 2) the amount of crustal thinning beneath the basin, 3) the amount of attenuation, and 4) The presence of a water layer. The effects of many of these features are indicated by the synthetic seismograms in Figure 4.

We began our sensitivity analysis by replacing the Mediteranean sea with sediments. Not surprisingly, the effects of this layer were relatively minor since only P-waves can propagate within it. The most noticeable difference was a lack of high-frequency energy riding on top of the late arriving, dispersed surface waves. Since the effects of this change on the regional phases was relatively minor, we left out the Mediteranean sea in many of our simulations.

The deep sedimentary basin was found to have the most significant effects on the regional phases. When the maximum basin thickness was reduced to approximately 5 km, Pg and Sn amplitudes were increased dramatically and the amount of surface wave dispersion was decreased dramatically. Reducing the amount of crustal thining decreased Pn and increased Pg and Sn, but not nearly as dramatically as the sedimentary basin. Based on differences between a model with and without attenuation, the effects of attenuation can be accurately approximately by a low-pass filter.

These result show how we can use simulations to understand observed regional wave propagation phenomena and suggest that it may be possible to predict the behaviour of regional phases and discriminants when we have a reasonably accurate model for the regional seismic structure.

The influence of two-dimensional topography on regional phases

Recent studies by Zhang and Lay (1995), Rodgers et al., (1997), and Hartse et al., (1997) have found significant correlations between the variability of regional discriminants and free-surface topography. However, it is not clear whether the observed correlations are due to topography or some highly correlated parameter of the underlying geologic structure. We have developed and begun implementing the capability to test the hypothesis that a significant portion of the variability of regional discriminants is due to free surface topography. Our initial simulations are for profiles of the highly variable topography to the west of the Caspian Sea (Figure 5). The topography we used is based on the approximately 1 km sampling, African digital elevation map from USGS, EROS data center. We accounted for potential effects of short wavelength variation in topography by interpolating to a higher spatial sample rate using fractal statistics. The underlying velocity structure is based on a one-dimensional model from Campillo (1990). This model is undoubtedly inappropriate for these profiles but we considered it useful for preliminary hypothesis testing. The resulting sythetics for models with and without topography are shown in Figure 6. The most noticeable result is the difference in the amplitude and duration of Lg and the Pg and Lg coda on the vertical components. When topography is present, the Lg and coda amplitudes and durations are enhanced significantly by the effects of scattering and mode conversion at the free-surface. These observations suggest that topography is a plausible mechanism for significant Lg generation and may be responsible for the relatively homogeneous nature of three-component regional waveforms.

Conclusions

We have developed and are utilizing state-of-the-art, elastic, finite-difference wave propagation modeling capabilities to understand the physical basis of regional wave propagation phenomena. Understanding the physical basis of these phenomena is essential for developing transportable seismic identification techniques and for predicting the behavior of regional phases in relatively aseismic regions. Based on modeling of data in the vicinity of the Eastern Mediteranean, we find that regional phases (body waves, guided waves, and surface waves) are very sensitive to the existence of deep sedimentary basins. Crustal thining also affects the regional body and guided waves but to a much lesser degree. The effects of attenuation are well approximated by a low-pass filter. The effects of the water layer were small but most noticeable in the later arriving surface waves.

We investigated the effects of topography for profiles to the west of the Caspian Sea. These simulations show that topography can increase the amplitude and duration of Lg and Pg and Lg coda via significant scattering and mode conversions at the free surface. These results suggest that free-surface topography may be responsible for significant generation of Lg and coda waves and may also explain the relatively homogeneous nature of three-component regional waveforms.

References

Barazangi, M., D. Seber, E. Sandvol, M. Vallve, 1995, “Digital database development and seismic characterization and calibration for the Middle East and North Africa”, PL-TR-96-2222, Phillips Lab., Hanscom AFB, Massachusetts, pp. 63.

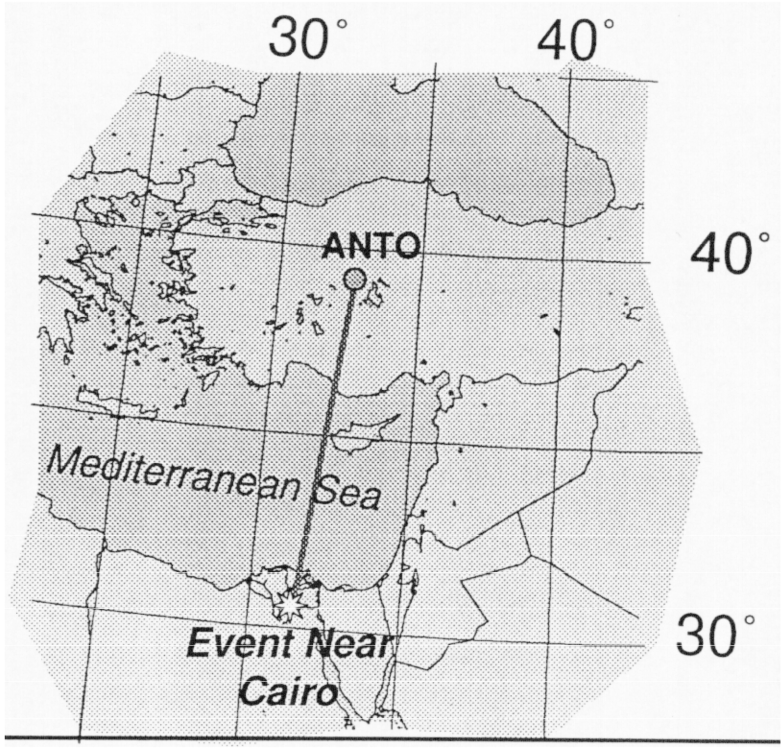

Figure 1. Map showing locations of the Mb 5.9, October 12, 1992 Cairo, Egypt earthquake and the seismic station at Ankara, Turkey (ANTO).

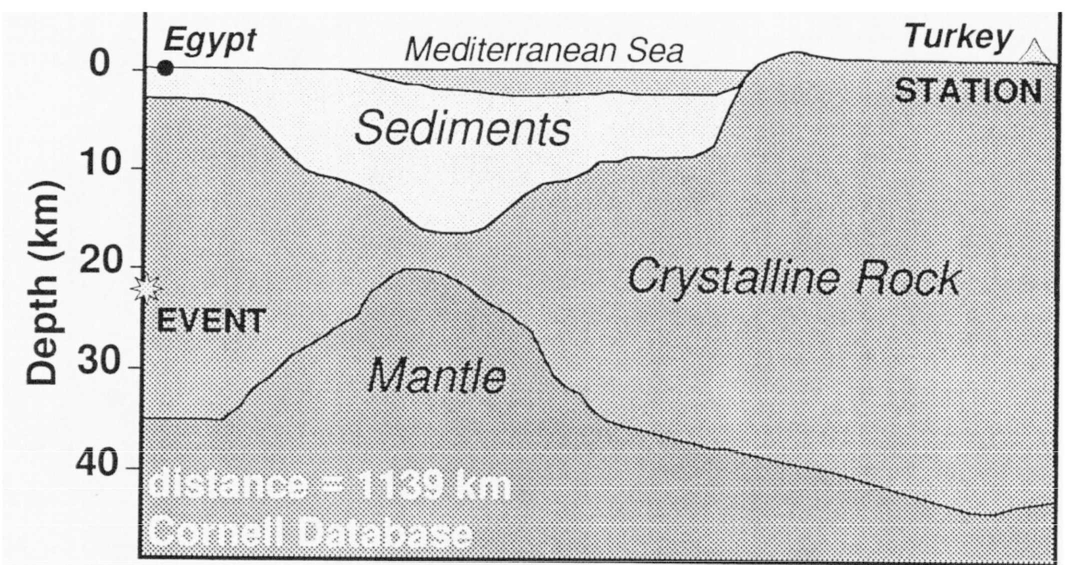

Figure 2. Cross section of crustal structure used to simulate wave propagation between Cairo, Egypt and Ankara, Turkey. The earthquake location is indicated by the star along the left boundary. The seismic station ANTO is indicated by the triangle near the upper right corner.

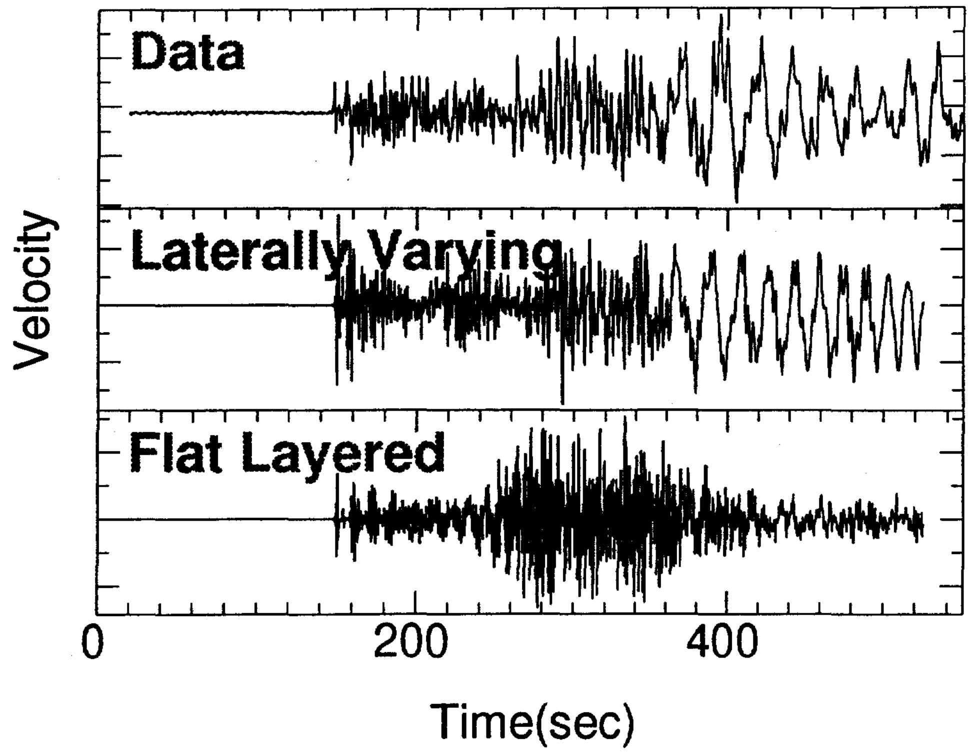

Figure 3. Comparison of vertical component data and synthetics for the Mb 5.9, October, 1992 Cairo, Egypt earthquake. The synthetic seismogram based on the laterally varying earth model provides a much better fit to the data.

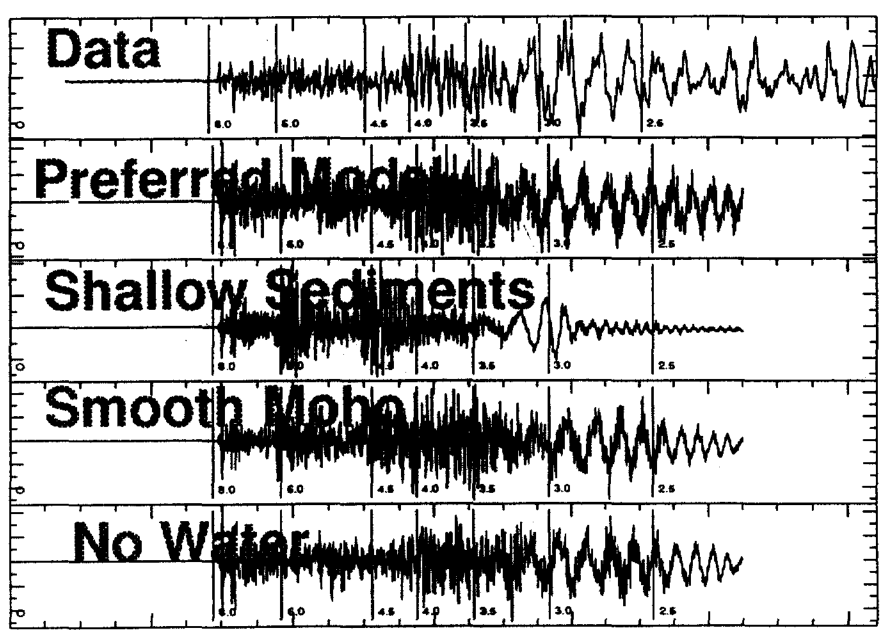

Figure 4. Comparison of vertical component data with synthetics for our preferred model, and models with shallow sediments, a smooth moho, and no water layer. Removing the shallow sediments from the preferred model has a dramatic effect on the agreement with the observed data.

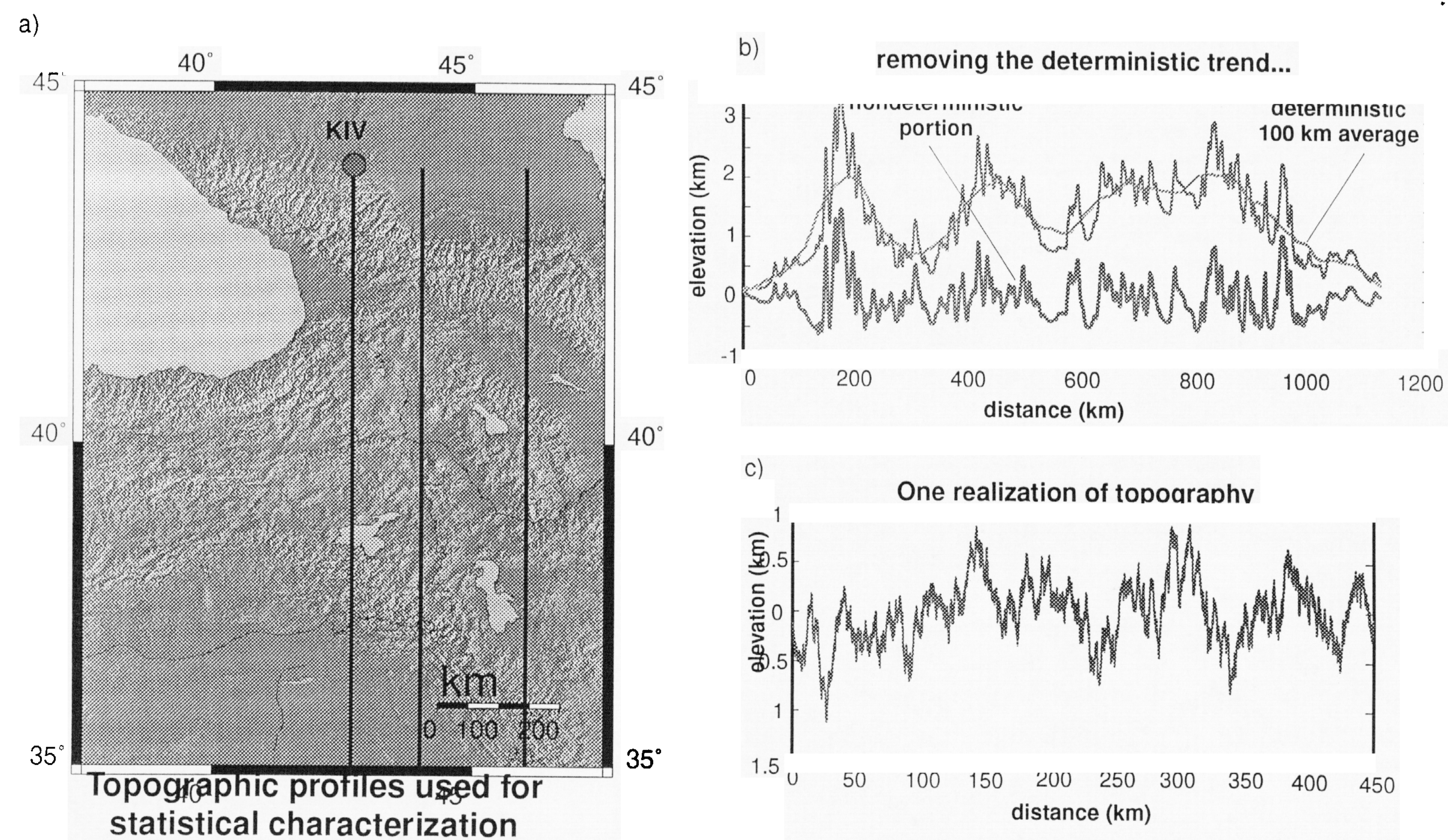

Figure 5. Locations and profiles of topography in the Caspian Sea region. a) Map showing location of the topographic profiles. b) Deterministic and statistical portions of observed topography. c) One realization of the statistical portion of topography, interpolated to a finer scale using fractals.

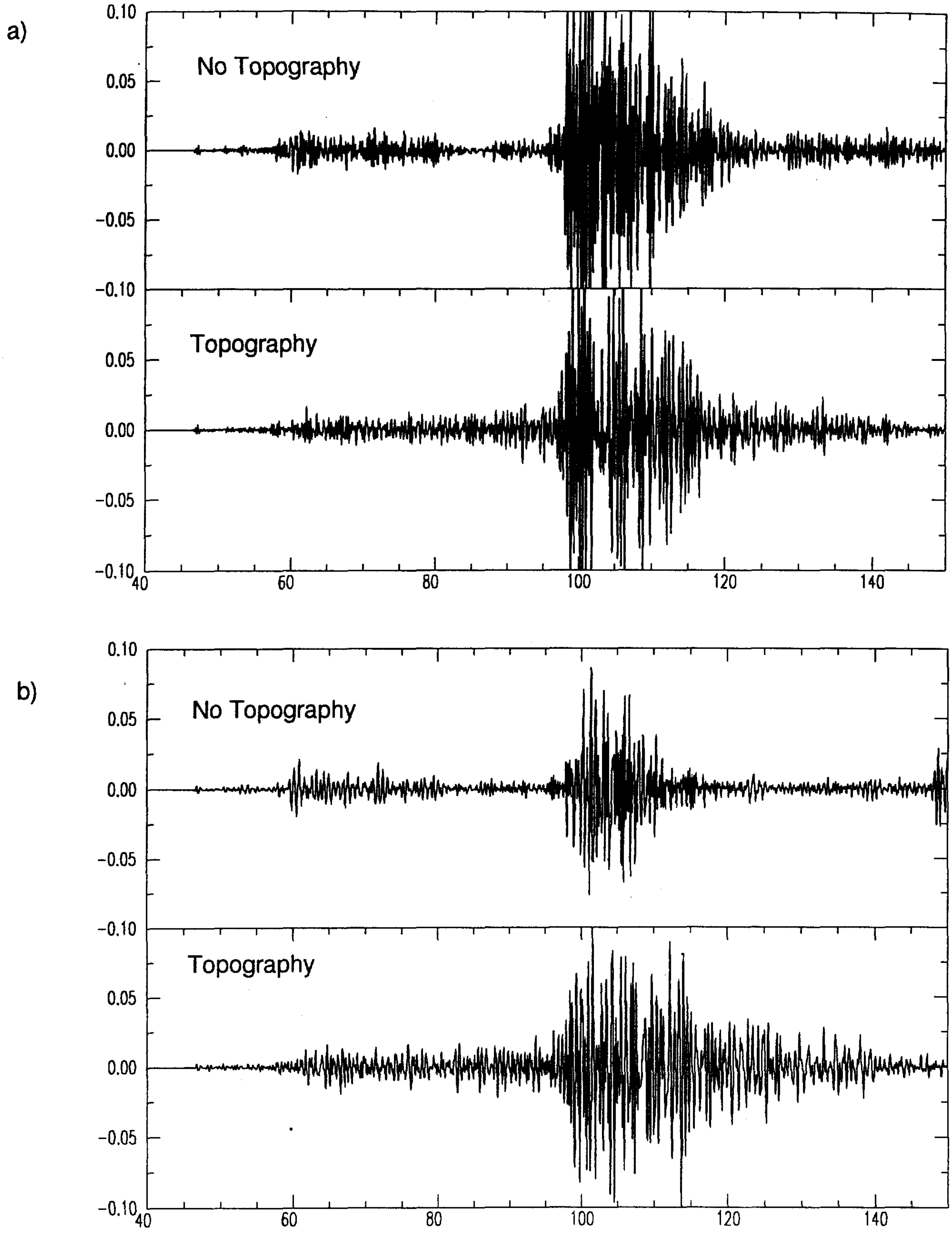

Figure 6. Comparison of simulations with and without topography. a) Radial components. b) Vertical components. Lg is significantly larger on the veritical component of the simulation with topography because of scattering and mode conversions at the free-surface.

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University of California • Livermore, California 94551