Application of seismic interferometry to attenuation estimation on zero-offset vertical seismic profiling data

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Although seismic attenuation measurements have great potential to enhance our knowledge of physical conditions and rock properties, their application is limited because robust methods for improving both the resolution and accuracy of attenuation estimates have not yet been established. In general, it is difficult to improve both the resolution and accuracy of attenuation estimates because there is a relationship of trade-off between them. Thus, the development of a robust method for improving both the resolution and accuracy of attenuation estimates is important. A zero-offset VSP measurement is considered to be best suited for attenuation studies as it enables sampling of the downgoing wavefield at various known depths because the downgoing waveform in a zero-offset VSP data set provides direct observations of the changing nature of the source wavelet as it propagates through the Earth. We propose attenuation estimation methods for zero-offset vertical seismic profile (VSP) data by combining seismic interferometry (SI) and the modified median frequency shift (MMFS) method developed for attenuation estimation using sonic waveform data. One important advantage of the application of SI to seismic exploration is that it allows flexibility of the source and receiver configurations. For example, this means that by applying SI to two different seismic traces recorded at different receivers, a new seismic trace with one receiver acting as a source (virtual source) and the other acting as a receiver can be created. The configuration of zero-offset VSP data is redatumed to that of the sonic logging measurement by adopting two types of SI: deconvolution interferometry (DCI) and crosscorrelation interferometry (CCI). Then, we can apply the MMFS method to the redatumed VSP data. Although the amplitude information estimated from CCI is biased, we propose a correction method for this bias to correctly estimate attenuation. First, to investigate the performance both in resolution and accuracy, we apply different trace separations to synthetic data with random noise at different signal-to-noise ratio (SNR) levels. Second, we estimate the influence of residual reflection events after wavefield separation on attenuation estimation. The proposed methods provide more stable attenuation estimates in comparison with the spectral ratio (SR) method because the mean-median procedure suppresses random events and characteristic features caused by residual reflection events in spectral domain. Our numerical experiments also demonstrate that the MMFS methods identify impulsive attenuation values caused by transmission loss due to reflection at an interface while such impulsive values are not observed in SR methods. This is because the SR method derives attenuation estimates based on frequency component change between two receiver depths while the MMFS method uses the amplitude variation, implying that the proposed methods can estimate scattering attenuation values from amplitude information even if frequency components are not changed between the two receiver depths. By preliminarily applying the proposed methods to field VSP data, we find some differences in the depth resolution and stability of attenuation values between the proposed method and the SR method, demonstrating that the proposed methods are more stable than the SR method especially in the shortest receiver separation. The responses of attenuation results obtained by applying different attenuation estimation methods to field data at different receiver separations correlate with those in our numerical experiments. To further verify and extend the applicability of the proposed method, one of future works should focus on validation of obtained attenuation results by comparing a seismic trace or its spectrum before and after attenuation compensation by inverse *Q* filtering. In our case,

a component of attenuation due to scattering effects is also included in the obtained attenuation estimates and thus such scattering effects should be taken into account in attenuation compensation. This attenuation compensation process might be used to estimate the scattering effects. To this end, a study to further investigate the response of the proposed methods to seismic scattering effects which are frequency dependent could be useful in providing new perspectives on the usage of the proposed method.

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