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Short-term synchronous and asynchronous ambient noise tomography in urban areas: Application to Karst investigation

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Karst disasters pose a substantial threat to geological environmental stability, resulting in ground collapse and groundwater contamination. To determine the spatial distribution of karst terrain, high-resolution underground imaging is essential. However, traditional synchronous observation systems struggle to achieve high-density spatial sampling due to limitations in instrument quantity. In this study, we conducted short-term synchronous and asynchronous ambient noise observations in a deserted parking lot in Hangzhou, China, to overcome the limitations of insufficient sampling density. We performed the first-round observation on one half of the parking lot for around 24 hours, followed by an immediate relocation of the stations to the other half for the second-round ~24-hour observation. Additionally, 29 fixed stations were placed outside the parking lot to continuously record ambient noise.

The imaging results of noise source distribution indicate that high-frequency noise sources exhibit significant non-uniform distribution during the daytime, which could affect the accuracy of the retrieved surface waves. To address this, we propose using the similarity of cross-component cross-correlation functions to select only data segments with stronger in-line noise sources, thereby enhancing the reliability of synchronous cross-correlation functions. Furthermore, we utilized the cross-component cross-correlation stacking method to suppress higher-mode surface waves and reduce their impact on the accuracy of the computation of asynchronous cross-correlation functions. Applying the ambient noise source-receiver interferometry method to the synchronous cross-correlation functions, we successfully retrieved the surface waves between asynchronous stations. In total, we obtained 66,472 pairs of cross-correlation functions, comprising 38,416 synchronous pairs and 28,056 asynchronous pairs. We extracted phase velocity dispersion curves of the fundamental mode surface wave for station pairs within the parking lot and utilized the direct surface wave tomography method to obtain the subsurface 3D shear-wave velocity structure.

The inversion results revealed the presence of two distinct low-velocity anomalies in the northeastern and southwestern parts of the site at depths around 40 m, which align with the location and depth of karst caves obtained from drilling data, confirming the reliability of the inversion results. Furthermore, we uniformly subsampled half of the data to simulate the case of insufficient station quantity, and the inversion model exhibited less apparent responses to the low-velocity anomalies, emphasizing the necessity of dense array observations. This study demonstrates that the combined observations of synchronous and asynchronous ambient noise can be utilized for high-resolution imaging of karst characteristics.