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New measures of tremor signals associated with eruptions and lahars

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Tremor signals are observed at volcanoes during heightened eruption activities and debris flows or lahars. Quantifying these signals is important in understanding dynamic processes associated with eruptions and lahars as well as monitoring these activities. The reduced displacement (RD) has been traditionally used as a measure of tremor. However, there are two main problems in the reduced displacement to quantify the size of tremor: (1) the frequency is not defined in estimating RD, and (2) the duration of tremor is not considered. In this study, we propose new measures of tremor signals using high-frequency seismic amplitudes. We use the amplitude source location (ASL) method utilizing high-frequency amplitudes under the assumption of isotropic S-wave radiation for tremor signals. We first estimate the source amplitude (SA) using vertical envelope amplitudes band-passed between 5 and 10 Hz and averaged over a 10-s window that includes maximum amplitudes. We then multiply the correction factor for the geometrical spreading and medium attenuation to the observed vertical waveform, and integrate in time its envelope amplitude with a passband of 5-10 Hz. We estimate the offset value of the integrated envelope amplitude during tremor, which we call the total source amplitude (TSA). SA and TSA may be related to the maximum mass flow rate and total mass volume involved during tremor, respectively. We estimated SA and TSA for tremor signals observed at Tungurahua and Cotopaxi volcanoes, Ecuador. We found that TSA linearly increases with increasing SA for lahar tremor signals, whereas TSA exponentially increases with increasing SA for eruption tremor signals. SA and TSA may be used as universal quantitative measures of tremor signals observed at different volcanoes.