Frequency Dependency of the Peak Energy Ratios for Teleseismic P Waves at the Hi-net Stations

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Subsurface heterogeneity in seismic velocity is an important aspect for understanding the seismotectonic setting of a region. Large scale heterogeneities are often studied using for example seismic tomography. On the other hand, smaller scale heterogeneities can be inferred from the scattering of seismic waves.

Peak energy ratio is a measure for the strength of small-scale heterogeneities, and is defined as the ratio of the maximum energy of P wave in the transverse component seismogram, to the sum of the maximum energy in the transverse, radial, and vertical components. According to Sato (2006), the peak ratio can be approximated as 1.81 $\varepsilon^2 z/a$ where ε, z, and a are fractional fluctuation in seismic velocity, thickness of the heterogeneous medium, and correlation distance respectively. Kubanza et al., (2007) used the peak ratio to quantify small-scale velocity heterogeneities on a global scale. In Japan, Nishimura (2012) estimated the peak ratios and found that non-active regions such as those far from volcanoes, yield smaller peak ratio, albeit still larger than at stable continents. Nishimura (2012) noted that the peak ratios generally increase with frequency, but did not quantify this observation. In this study, we quantify the frequency dependency of the peak ratio and discuss its relations to Japan's tectonic setting.

Data from 803 stations and 99 earthquakes, recorded for the period between 2010 and 2019, were considered for this study. Teleseismic events with magnitude and depth of 5-6.5 and >300 km respectively were used, ranging between 0°-60° epicentral distance. We discarded any source-receiver pair with less than 10 signal-to-noise ratio, and calculated the mean-squared envelopes. Finally, we stacked the envelopes for all stations that record >10 earthquakes.

Results show that there is a divide in scattering properties over Japan, where larger peak ratios can be found on east Japan. This was previously obtained by Nishimura (2012) and successfully replicated here. Uncertainty is calculated using the Jack-Knife test, presented as the coefficient of variation, with error on average considerably less than 5%. We perform the analysis under four frequency bands: 0.5-1; 1-2; 2-4; and 4-8 Hz, and observe an overall increase in peak ratio with frequency similar to Nishimura (2012). To analyse the frequency dependency in our results, we define *frequency gradient* as the gradient, m of the trendline $\log p = m \log f_c + a$ where p is the peak ratio, and f_c is the central frequency of each frequency band.

There is a seeming pattern of the frequency dependency in relation to the volcanic front. Stations located on the West/back-arc show steeper frequency gradient hence stronger frequency dependency. We look into Kanto-Tokai, Tohoku, and Kyushu where the traces of the volcanic front are more conspicuous. We performed the t-value test to determine that statistically, western peak ratios are more dependent on frequency, for Kanto-Tokai, Tohoku, and Kyushu. We also did the Pearson's χ^2 test to confirm the perceived visual pattern of high correlation to the West and vice versa at Kanto-Tokai and Tohoku. For Kyushu, the visual impact is not as discernible as the others even though the difference in East and West frequency gradients is statistically significant.

There are possible scenarios that might explain this frequency dependency. If the pattern mostly reflects the scattering in the deeper lithosphere, then this contrast can be attributed to the more inhomogeneous

velocity structure of the mantle wedge in the back-arc where rich small-scale heterogeneity region scatters high frequency seismic components more strongly than lower frequencies. This accordingly increases the profoundness of the scattered P wave contribution into the transverse seismogram at higher frequencies. On the other hand, the makeup of the transverse seismogram is mostly influenced by scattering in the shallow depth, which would imply impressions from shallow structures such as sedimentary plains. This only further emphasizes the needs to study the depth dependency in scattering heterogeneity, for example, by combining teleseismic and local events to model the seismogram envelope using the Monte Carlo simulation. This will be the premise for our future works.

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