Tsunami Scattering due to Randomly Fluctuating Sea-Bottom Topography; Scattering Attenuation and Coda Excitation

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The present study theoretically derives scattering coefficient for tsunami propagation in randomly fluctuating sea-bottom topography to evaluate scattering attenuation and coda (later phase) excitation of tsunamis. Scattering plays an important role on tsunami propagation through ocean. For example, the leading wave of the 1960 Chilean tsunami was estimated to be attenuated by 40% due to the scattering during the propagation from Chile to Japan [Tsuji 1977]. In the 2006 Kuril event, the scattered waves which arrived at 10 hours later from the onset of the first tsunami arrival constitutes the maximum tsunami height along the eastern coast of Japan, and it caused the miss clearing-alert [Koshimura 2007]. National Oceanic and Atmospheric Administration (NOAA) in the USA made the tsunami scattering potential maps in the Pacific Ocean [Mofjeld 2001]. Estimating tsunami scattering and know their properties are necessary for mitigating tsunami disasters. In estimating scattering properties, the past study usually modeled sea mount as a simple geometry such as cylindrical shape or a circular shape [e.g. Tsuji 1977; Mofjeld et al. 2000]. On the other hand, it is well known that the sea-bottom topography shows fractal behavior, and its spectrum is characterized by power law [e.g. Turcotte 1989].

Supposing that the sea-bottom topography randomly fluctuates in space according to a power law, we theoretically derive the scattering coefficient for linear long-wave tsunami equations. The method was originally developed in radio-wave [e.g. Chernov 1960] and seismic-wave scattering problems [Aki and Richards 1980; Sato and Fehler 1998]. For tsunami scattering problems, the water depth is constituted of the average depth h0 and the fluctuation xi. When the xi is small, the relation between the scattering wave and the xi is obtained by using the Born approximation. By taking ensemble average with respect to the power of scattering waves, the scattering coefficient (power of scattering and its radiation pattern with respect to unit area) is represented by the power-spectrum of the sea bottom fluctuation xi.

The scattering coefficient depends on the tsunami wavelength. When the wavelength is small (compared to the correlation distance of the topography fluctuation), the radiation pattern shows strong forward scattering. On the other hand, when the wavelength is large, the radiation pattern approaches to isotropic. But the scattering in the lateral directions is always small irrespective of the wavelength. The back scattering coefficient can be a measure for coda wave excitation. When the sea-bottom topography is characterized by power law with the exponent of -p, the coda energy Ecoda is proportional to f- -p+3 where f is the frequency. When p = 2, which was estimated from sea-bottom topography data [Turcotte 1989], the tsunami coda energy Ecoda increases with increasing the wavefrequency. Furthermore, we estimate the scattering attenuation represented by quality factor Q^{-1} from the scattering coefficient following the method of Sato [1982]. The value of Q^{-1} increases proportional to f^2 when the wavelength is large, and becomes independent of the frequency when the wavelength is small if we use p = 2.

This study derives a theoretical relation between tsunami scattering and the sea-bottom fluctuation, where both the wavelength and the corresponding components of the bottom fluctuation are included. This is different from the method employed in Mofjeld et al. [2001] where the scattering potential at a point is estimated only from the depth at the point. As next step, it would be important to apply our method to investigate tsunami scattering properties using the spectrum of the sea-bottom fluctuation at various regions.