P012

Radiation Pattern Model for High Frequency Ground Motion

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Abstract

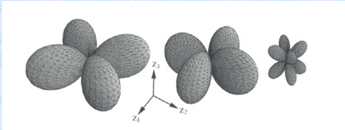
The source radiation pattern has been traditionally assumed independent of the azimuth and take-off angle at high frequencies. However, analyses from recent earthquakes have shown that the radiation pattern dependence on the azimuth is still important for frequencies close to 1 Hz and fade away for frequencies larger than 3Hz. In the present study we propose a frequency dependent radiation pattern model that introduces a smooth transition from the theoretical source radiation pattern at low frequencies (non-spherical radiation) to a complete spherical radiation at high frequencies (>3Hz). The model is applied to the 2000 Tottori earthquake and compared with other high frequency radiation pattern models available.

The proposed model efficiently eliminates the dependence of the radiation pattern coefficient on the azimuth and take-off angle as the frequency increases.

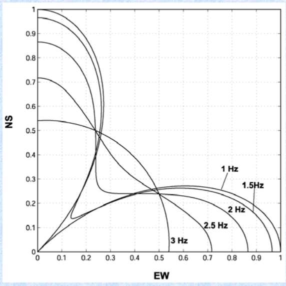
I Frequency dependent radiation pattern models

Analysis from recent earthquakes have shown that for the intermediate frequency range (1 to 3Hz) the ground motion radiation pattern shows a dependence on the azimuth that disappear for high frequencies.

Non spherical radiation for a point-shear dislocation source (from Sato and Fehler)



SH Radiation pattern dependence on frequency for a pure strike-slip fault



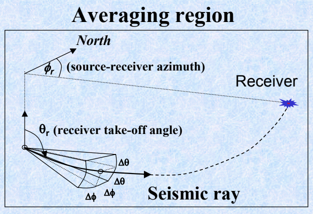
Average radiation pattern coefficient

(Boatwright et. al. 1984)

$$R_p(\theta,\phi,f)=\frac{\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} G(\theta,\phi)\sin\theta\, d\phi\, d\theta}{\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2}\sin\theta\, d\phi\, d\theta}$$

G: radiation pattern coefficient for the appropriate wave

Averaging region



Kamae (1990)

Take-off angle

$$\theta_r=\pi/2$$

Azimuth

$$\phi_1=\phi_r-\pi/4(f-f_1)/(f_2-f_1)$$
$$\phi_2=\phi_r+\pi/4(f-f_1)/(f_2-f_1)$$

Pitarka (2000)

Take-off angle

$$\theta_1=\theta_r-\pi/6(f-f_1)/(f_2-f_1)$$
$$\theta_2=\theta_r+\pi/6(f-f_1)/(f_2-f_1)$$

Azimuth

$$\phi_1=\phi_r-\pi/3(f-f_1)/(f_2-f_1)$$
$$\phi_2=\phi_r+\pi/3(f-f_1)/(f_2-f_1)$$

Several models have been proposed, in order to smoothly reduce the dependence of the radiation pattern on the azimuth and take-off angle as the frequency increases. For that purpose the radiation pattern for some particular receiver is calculated by averaging all the rays in a region around its azimuth and take-off angle. The averaging region is gradually enlarged from 0° to +/- 60° (Pitarka) and +/- 45° (Kamae) around the azimuth, and +/- 30 (Pitarka) and 0 (Kamae) around the take-off angle, as the frequency increases. In the case of Kamae the radiation pattern is calculated for a fixed take-off angle, and is only dependent on the azimuth.

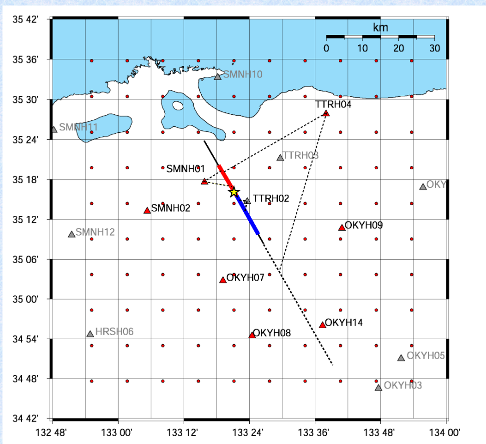
Proposed model

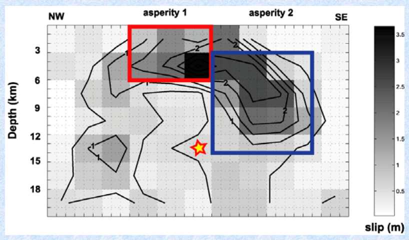
$$R_{ave}=\frac{\int_{\pi/2}^{\pi}\int_{0}^{2\pi} G(\theta,\phi)\sin\theta\, d\phi\, d\theta}{\int_{\pi/2}^{\pi}\int_{0}^{2\pi}\sin\theta\, d\phi\, d\theta}$$

$$R_p(\theta,\phi,f)=G(\theta,\phi)+(f-f_1)/(f_2-f_1)(R_{ave}-G(\theta,\phi))$$
$$\text{if } G(\theta,\phi)\le R_{ave}$$
$$R_p(\theta,\phi,f)=R_{ave}+(f_2-f)/(f_2-f_1)(G(\theta,\phi)-R_{ave})$$
$$\text{if } G(\theta,\phi)>R_{ave}$$

The proposed model differs from previous models in that no averaging region around the azimuth and take-off angle is used, in order to smooth out the radiation pattern as the frequency increases. The first step is to calculate an average radiation pattern coefficient for all rays departing in the upper focal sphere, which corresponds to the near field region. The second step is to calculate the theoretical low frequency radiation pattern coefficient at some particular station and gradually smooth it out to the constant value obtained previously (spherical radiation) with a linear dependence on the frequency.

II Application to the 2000 Tottori-ken Seibu earthquake





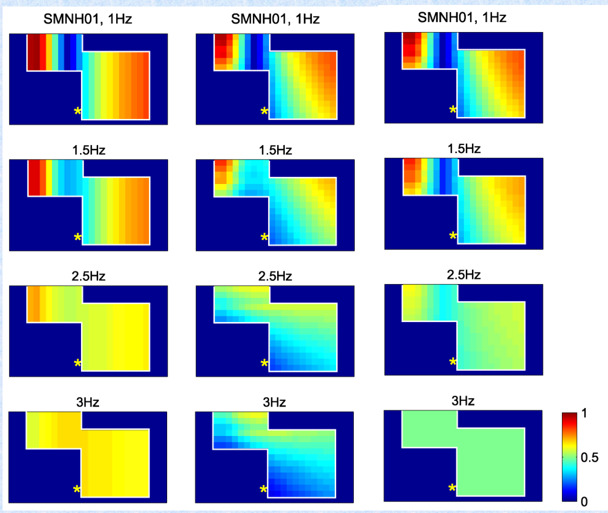
Simulation target region and asperity model used for the calculation of the frequency dependent radiation pattern coefficients. Slip model from Iwata et al. 2000.

III Radiation pattern coefficient SH-waves across the fault plane for a particular receiver

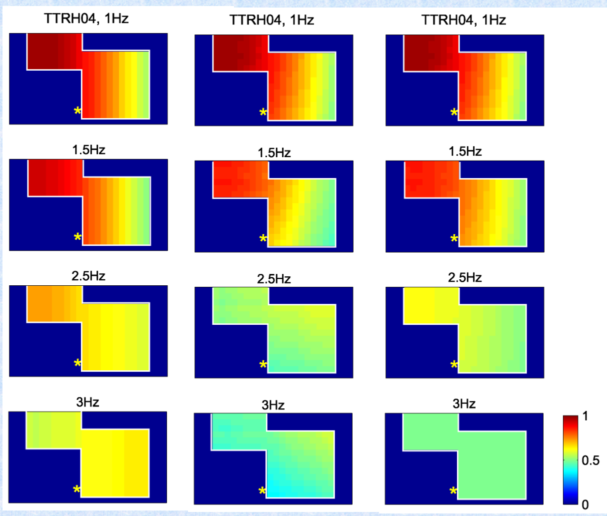
We calculated the SH-waves radiation pattern variation across the fault plane, for the near fault KiK-Net stations during the 2000 Tottori earthquake. Three different radiation models are compared.

We can observe that the model proposed efficiently removes the dependence on the azimuth and take-off angle as the frequency increases. We also can observe that the radiation pattern coefficient sistematicaly decreases with the increase in depth.

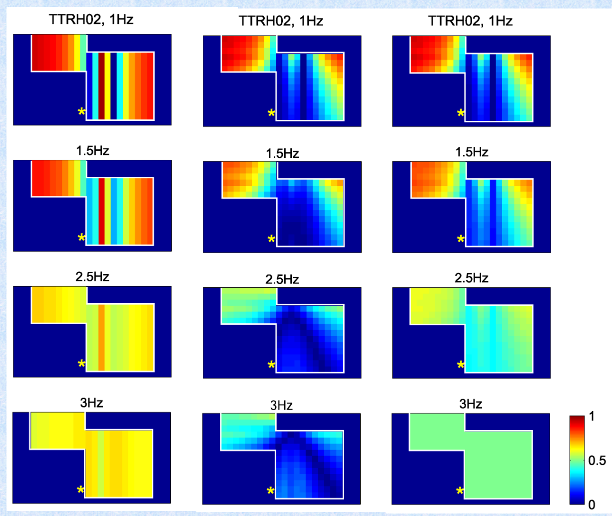
Kamae Pitarka This study



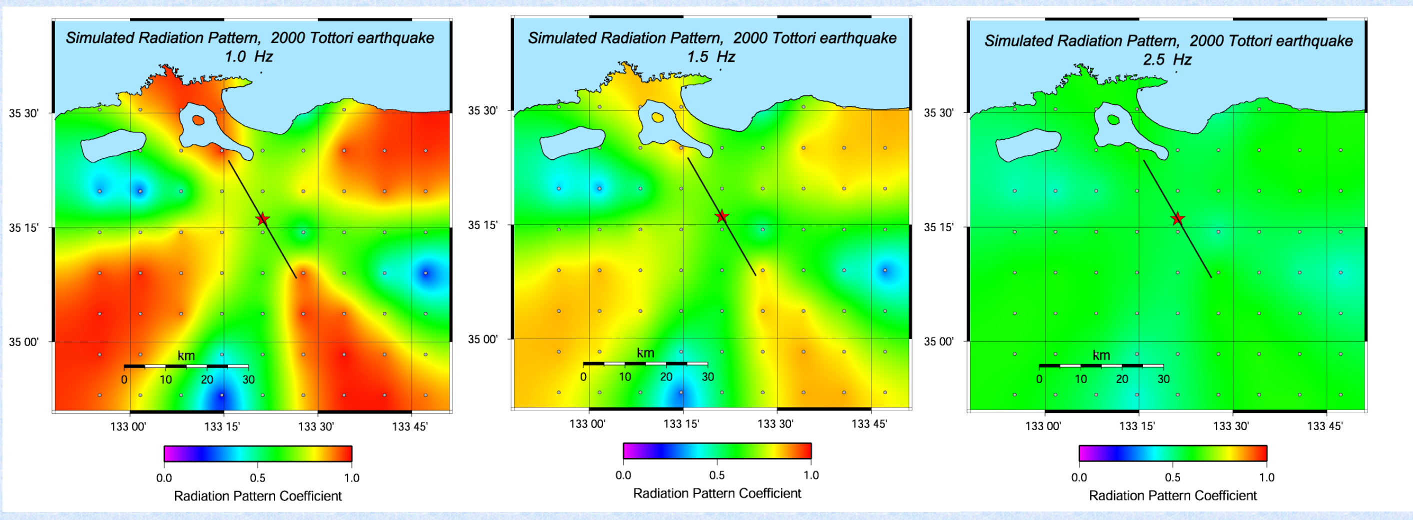
Kamae Pitarka This study



Kamae Pitarka This study



IV Average radiation pattern SH-waves



We calculated the radiation pattern at every receiver by averaging all the values inside the asperity region. The radiation pattern dependence on the azimuth is removed as the frequency increases. For distances larger than half the fault length from the epicenter, the average radiation pattern basically corresponds to the one from a double couple point source.

V Conclusions

We have proposed a source radiation pattern model that accounts for the transition between a non-spherical to a spherical source radiation as the frequency increases.

The model eliminates efficiently the dependence of the radiation pattern on the azimuth and take-off angle as the frequency increases.

Shallow sources radiate SH-waves more efficiently than deeper ones.