Approximation constant-Q reverse time migration in the time domain: Unsplit-field PML formulation

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Abstract

We investigate the simulation of wave propagation in attenuation medium within approximating constant-Q. Such wave propagation can be modelled with a finite difference scheme by introducing a series of standard linear solid (SLS) mechanisms, and it can be carried out within a computationally tractable region by making use of perfectly-matched layer (PML) boundary conditions. In the weak attenuation (Q = 100), the numerical solutions using a series of SLS relaxation mechanisms and analytical solutions agree very well, and the acoustic and viscoacoustic RTM images have similar artifacts and amplitudes in the shallow layers. At the deeper layers, we can see that a series of SLS mechanisms RTM yield comparable results with the acoustic RTM case. In strong attenuation (Q = 20), when the wave reaches greater depth, the error of numerical solutions using single SLS mechanism increase and the viscoacoustic RTM images using a single SLS mechanisms are not so accurate in the deeper layers. Although the results of single SLS relaxation mechanism are still useful for practical application, the three SLS relaxation mechanisms are quite accurate for both weak and strong attenuation.

Attenuation model

The almost constant quality factor is a quality factor at central of frequency band, $Q(\omega_0) = \bar{Q}$, thus

$$\bar{Q} = Q_0 L \left(\sum_{l=1}^{L} \frac{2\omega_0 \tau_{0l}}{1 + \omega_0^2 \tau_{0l}^2} \right)^{-1}$$

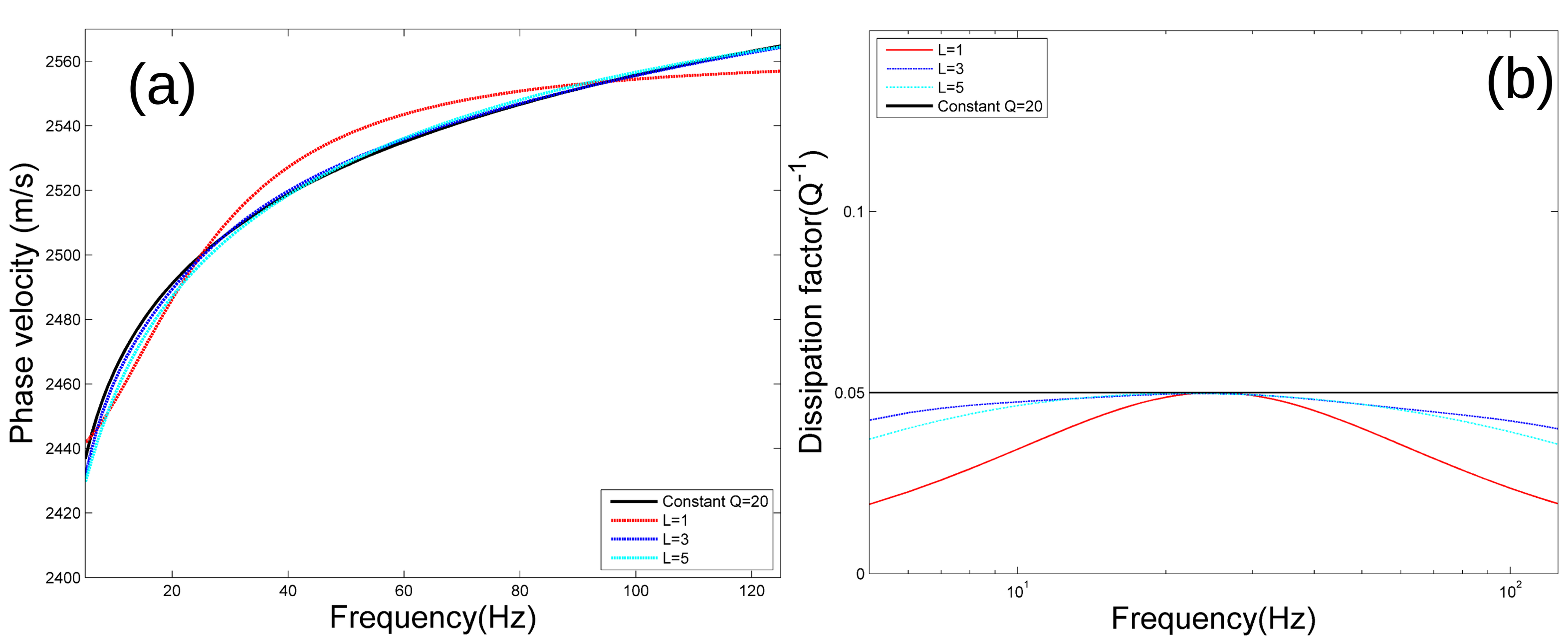

FIG. 1. The dissipation factor (a) and phase velocity (b) of constant Q = 20. The black line corresponds to constant Q = 20, red line corresponds to one SLS (Q0 = 20), blue line corresponds to three SLS (Q0 = 11.9), and cyan line corresponds to five SLS (Q0 = 13.1).

UN-split PML formulation for viscoacoustic medium

The unsplit-field PML equations of the GSLS model based viscoacoustic medium theory can obtain as

$$\frac{\partial P}{\partial t} = -K\left[\frac{\partial\left(u_x + d(z)u_x^{(1)}\right)}{\partial x} + \frac{\partial\left(u_z + d(x)u_z^{(1)}\right)}{\partial z}\right]\left[1 - \sum_{\iota=1}^{L}\left(1 - \frac{\tau_{\varepsilon\iota}}{\tau_{\sigma\iota}}\right)\right]$$
$$-[d(x) + d(z)]P - d(x)d(z)P^1 - \sum_{\iota}^{L} r_\iota$$

Numerical results

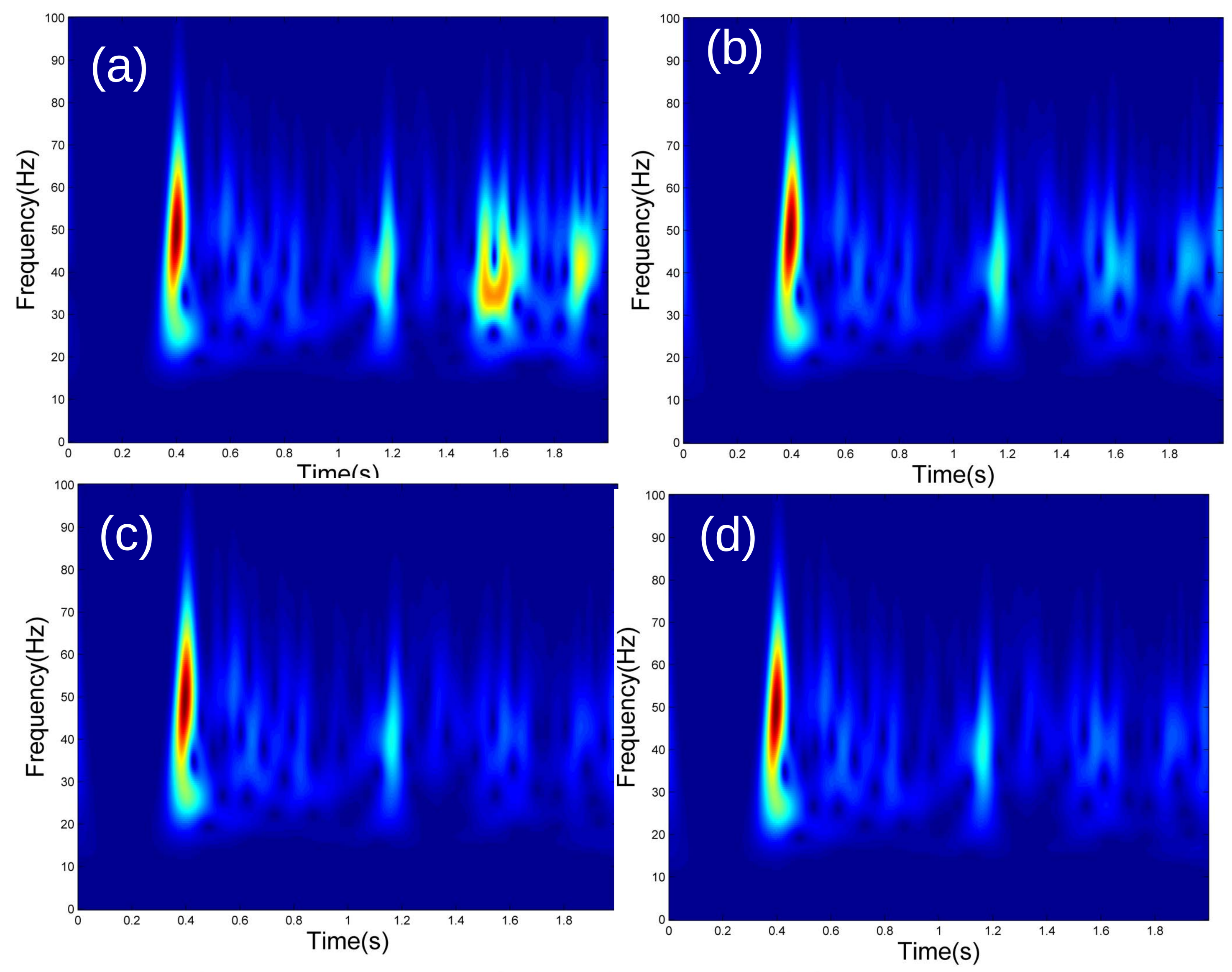

FIG. 2. The S spectrum of the shot record from acoustic simulation (a), viscoacoustic (L = 1) simulation (b), viscoacoustic (L = 3) simulation, and viscoacoustic (L = 5) simulation.

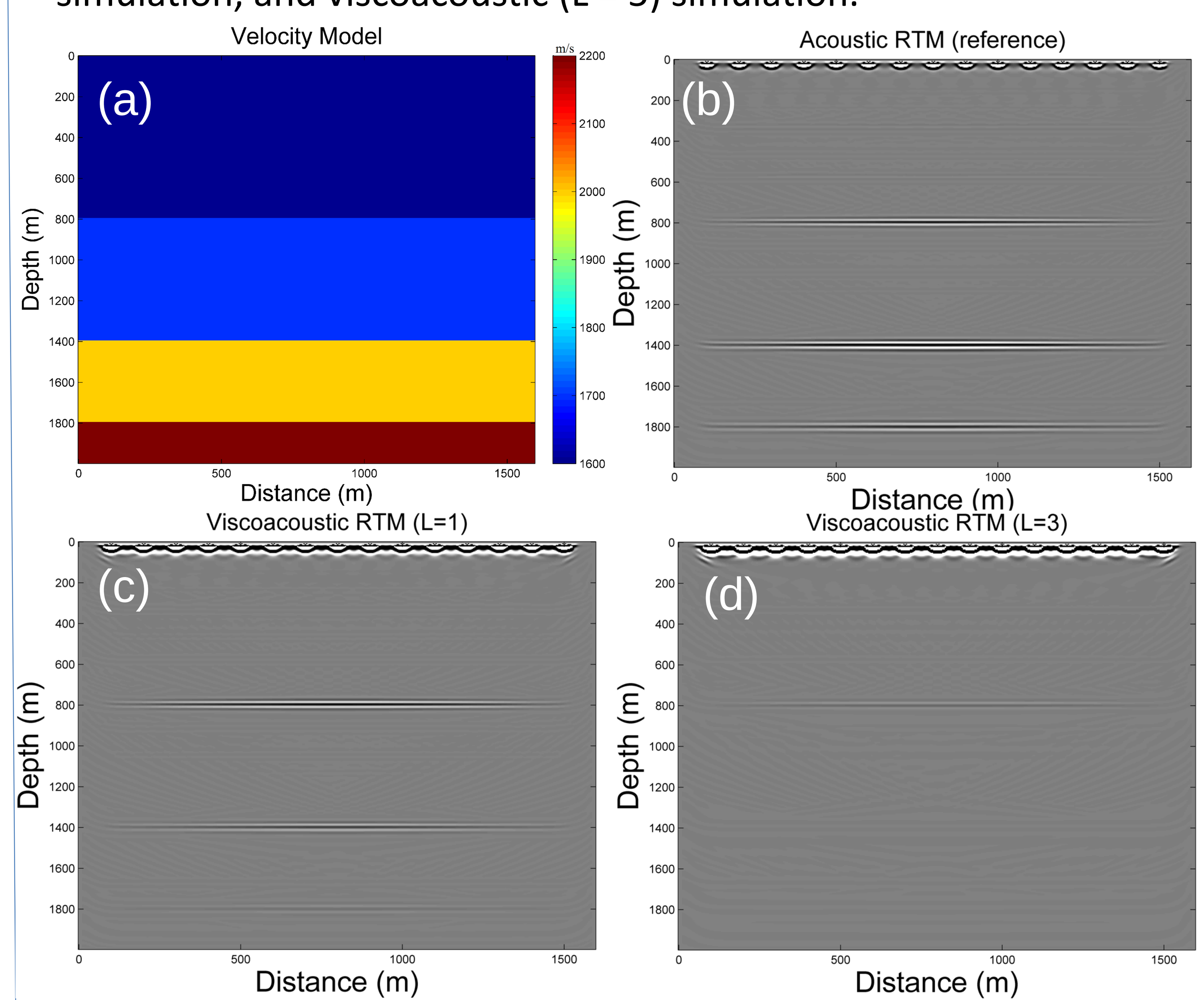

FIG. 3. The RTM images of the layered model (a)with background attenuation (Q = 20) (b) acoustic RTM (reference), (c) viscoacoustic RTM (L = 1), (d) viscoacoustic RTM (L = 3) and (b)viscoacoustic RTM (L = 5).

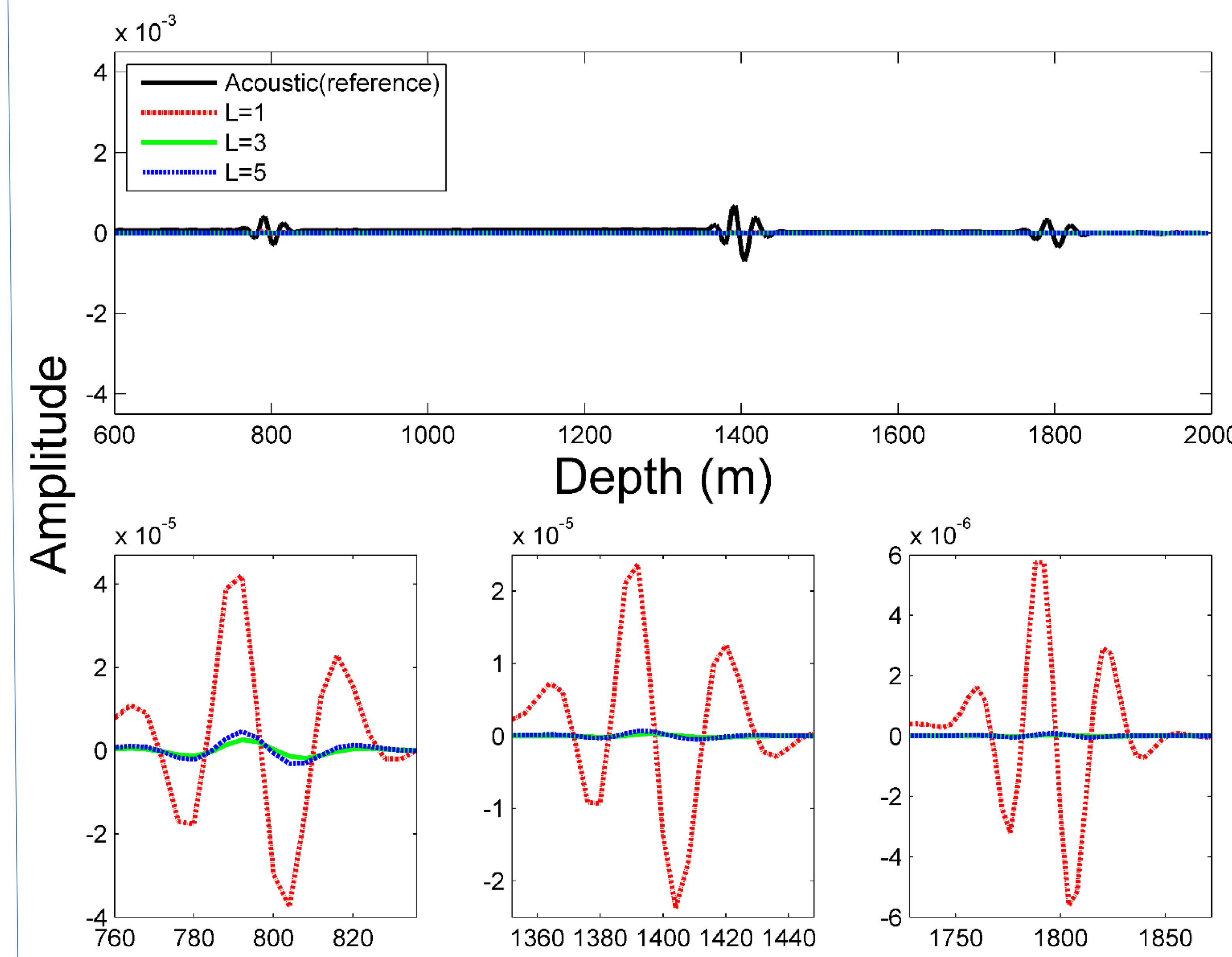

FIG. 4. Depth slices from Figure 15 showing the effect of attenuation and comparison of acoustic (Black solid line), viscoacoustic L = 1 (dashed red line), viscoacoustic L = 3 (green solid line), and viscoacoustic L = 5 (dashed blue line).

Conclusions

Time-domain approximate constant-Q wave propagation involving a series of standard linear solid (SLS) mechanisms is investigated. We found that the numerical results and analytical solutions using single and a series of standard linear solid (SLS) mechanisms in the weak attenuation medium agree very well. In strong attenuation when the wave reaches greater depth, the error of numerical solutions using single SLS mechanism increase and the viscoacoustic RTM images using a single SLS mechanisms are not so accurate. Although modeling of a single SLS relaxation mechanism is still useful for practical application and faster than three and five SLS mechanisms, the three SLS relaxation mechanisms are quite accurate for both weak and strong attenuation.

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