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Time-Domain Viscoacoustic Wave Equation Based on Kaniadakis κ-Deformed Statistics

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Introduction

Seismic waves when interacting with the subsurface suffer from two attenuation effects due to the anelasticity of the medium, which are phase dispersion and energy dissipation, impacting the resolution of seismic imaging techniques such as Reverse Time Migration (RTM) and Full Wave Inversion (FWI). In order to insert losses in the medium, we use a complex velocity model. With this, the quality factor Q arises, whose function is to quantify these effects on wave propagation. In this work, we develop a new viscoacoustic wave equation in the time domain based on κ-statistics, which effectively models wave propagation in attenuating media. This equation allows observing the phenomenon in different ways, since it is possible to decouple the phase dispersion and dissipation terms, being able to modify the simulation of medium attenuation through the Q factor, which is explicitly integrated into the equation. Therefore, this approach improves the accuracy of seismic modeling, ensuring better image quality and interpretation of underground structures.

Method

Initially, we treat the viscoacoustic wave equation in the frequency domain from the complex velocity model. In this step, we propose a Kaniadakis κ-logarithm approximation that simulates attenuation effects. Following this, we apply the inverse Fourier transform to obtain a new viscoacoustic wave equation in the time domain. The finite difference method is used to discretize the model in the computational domain. Furthermore, to fit the simulation of an attenuating medium, the quality factor Q is changed to observe how the wave propagation varies with the phenomena of phase dispersion and energy dissipation. Finally, we compare the numerical solution of the viscoacoustic wave equation in the time domain with the analytical Green's function in a homogeneous medium.

Results and Conclusions

The numerical results obtained show that the viscoacoustic wave equation in the time domain based on the κ-statistic simulates the effects of phase dispersion and energy dissipation at different Q values, especially at low quality factors where the attenuation effects are intense. As a way of validating the method, the numerical solution between the viscoacoustic wave equation in the time domain and the analytical Green's function is compared, showing that the method accurately describes the attenuation effects.