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Born序列频散方程和Born-Kirchhoff传播算子

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摘要 传统的Kirchhoff传播算子结构简洁，适用于描述横向均匀介质中波的传播.Ray-Kirchhoff传播算子较为精确地描述了波在非均匀介质中传播的运动学特征，其理论上的先天不足依赖于介质的复杂性.本文通过Born序列逼近波在非均匀介质中传播的大角度波分量，提出一种Born-Kirchhoff传播算子，将传统Kirchhoff传播算子的适用范围扩展至非均匀介质，同时描述波的运动学和动力学特征，其精度取决于Born序列逼近的阶数.利用Born序列频散方程，可以精确分析各阶Born-Kirchhoff传播算子对波长、传播角和非均质性的尺度依赖特征，其中，一阶Born-Kirchhoff传播算子的精度高于传统的相屏传播算子.波数域的Born-Kirchhoff传播算子对于高波数波是奇异的，导致波数域数值计算发散，但其空间域版本是非奇异的，无条件数值稳定，可通过Kirchhoff求和数值实施.本文给出各阶Born-Kirchhoff传播算子及其频散方程，可用于不同程度非均匀介质中的波传播模拟，复杂构造地震成像和速度估计.本文利用零阶和一阶Born-Kirchhoff传播算子计算简单二维模型的合成地震图，并与边界元法进行了比较.

关键词 波传播 Born序列逼近 Born序列频散方程 Born-Kirchhoff传播算子 非均匀介质

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Born-series dispersion equations and Born-Kirchhoff propagators

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Abstract Conventional Kirchhoff propagators are conceptually simple and applicable for wave propagation in laterally homogeneous media. Ray-Kirchhoff propagators are kinematically acceptable in the range of seismic frequencies for heterogeneous media, but theoretically suffer congenital deficiencies. In this paper we present a natural way to extend the conventional Kirchhoff propagators to heterogeneous media. The so-called Born-Kirchhoff propagators are designed in the wavenumber domain under Born-series approximation to account for large-angle waves in strong-contrast media. These wavenumber-domain propagators that usually become singular at high wavenumbers can be transformed into the space domain, which are unconditionally stable with the Kirchhoff-summation implementation. Various orders of the Born-Kirchhoff propagators are formulated with a target-oriented flexibility to handle local complex zones for wave propagation, seismic imaging, and velocity estimation. A complete accuracy analysis is conducted by Born-series dispersion equations to characterize the Born-Kirchhoff propagators' scale-dependence on wavelengths, propagation angles, and heterogeneities. Synthetic seismograms for a simple 2D model are calculated with the zeroth-order and first-order Born-Kirchhoff propagators in comparison with those generated by the boundary-element method.

Key words Wave propagation; Born-series approximation; Born-series dispersion equations; Born-Kirchhoff propagators; Heterogeneous media

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