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曲线坐标系程函方程的求解方法研究

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Study on the numerical solutions of the eikonal equation in curvilinear coordinate system

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摘要 笛卡尔坐标系中经典的程函方程在静校正、叠前偏移、走时反演、地震定位、层析成像等许多地球物理工作都有应用,然而用其计算起伏地表的地震波走时时却比较困难.我们通过把曲线坐标系中的矩形网格映射到笛卡尔坐标系的贴体网格推导出了曲线坐标中的程函方程,此时,曲线坐标系的程函方程呈现为各向异性的程函方程(尽管在笛卡尔坐标系中介质是各向同性的).然后尝试用求解各向同性程函方程的快速推进法和Lax-Friedrichs快速扫描算法来分别求解该方程.数值试验表明未加考虑各向异性程函方程与各向同性程函方程的差别而把求解各向同性程函方程的快速推进法直接拓展到曲线坐标中的程函方程的做法是错误的,而Lax-Friedrichs快速扫描算法总能稳定地求解曲线坐标系的程函方程,进而有效地处理了地表起伏的情况,得到稳定准确的计算结果.

关键词 程函方程, 起伏地表, 各向异性, 快速推进法, Lax-Friedrichs快速扫描算法

Abstract: The classical eikonal equation is commonly used in Cartesian coordinate system for problems that involve static correction, prestack migration, earthquake location and seismic tomography, but is less effective for calculating travel times in an earth model that has an irregular surface. We transform the eikonal equation to a curvilinear coordinate system that conforms with the boundaries of the domain. The eikonal equation in the curvilinear coordinate system displays the mathematical form of an anisotropic eikonal equations (even though the medium is isotropic in the Cartesian coordinate system). Then, we try to solve the anisotropic eikonal equations with two numerical methods, a simple modification of the fast marching method and Lax-Friedrichs fast sweeping method, respectively. Through a number of different numerical experiments we find: one may compute wrong solutions by extending fast marching methods designed for isotropic eikonal equations to anisotropic eikonal equations without taking into account the differences between them; the Lax-Friedrichs fast sweeping method is stable and valid for the eikonal equation in the curvilinear coordinate system, which has a significant meaning in the direction of solution of the eikonal equation in the curvilinear coordinate system.

Keywords Eikonal equation, Topography, Anisotropy, Fast marching method, Lax-Friedrichs fast sweeping method

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