How to Choose a Grid Resolution for FDTD Models Applied to GICs

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Motivation

In the interest of maintaining both civilian and military infrastructure, it is important to protect electric power grids, smart grids, low-voltage internet of things, and other electrotechnologies from known and possibly as-of-yet unknown space weather hazards. The finite-difference time-domain (FDTD) method is a robust and versatile method that has already been applied to the study of geoelectric fields and geomagnetically induced currents. The advantages of FDTD over other methods are that it can account for more geometrical complexities and realistic time waveforms. For example, it can account for the 3-D variations of the lithosphere composition and ocean-continent boundaries. It can also account for complex 3-D ionospheric currents. Previously, when applied to GICs, FDTD grids with relaxed grid resolutions in the horizontal direction were utilized for computational efficiency ([2], [4], [5]), since Snell's Law predicts that any electromagnetic waves should be propagating straight downwards into the low resistivity ground even when the electromagnetic waves are incident from a grazing angle with the ground. We investigate whether this assumption is correct and find that for accuracy, the horizontal (not just vertical) grid resolution should be <1/3 of a skin depth or <1/3 the size of each ground feature. We then propose a solution that may be applied to FDTD models on either a regional or global scale in order to maintain these requirements.

FDTD Modeling

- Solves Maxwell's equations in time and space
- Grid-based Time-domain method
- Computes the electric field directly, rather than calculating them from magnetic fields as for many space weather approaches

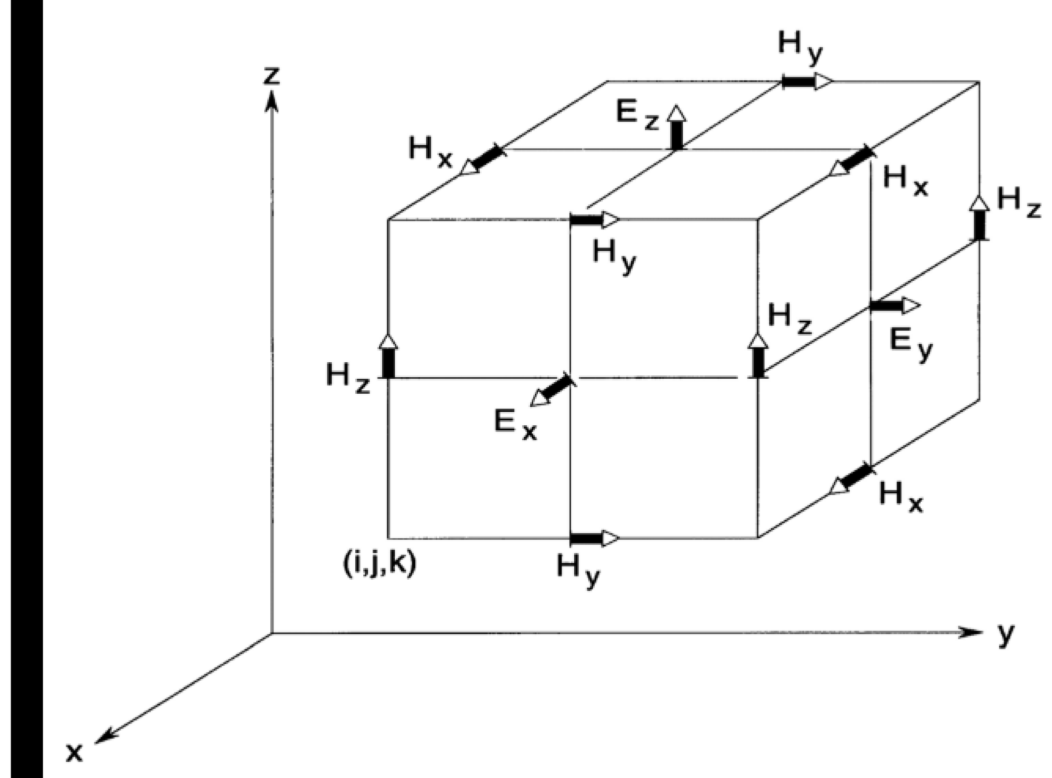


Fig: One grid cell of the 3-D FDTD model([1])

Geomagnetically Induced Currents (GICs)

Solar Activity (e.g., CMEs) → disturbs → Earth's magnetosphere → induces → Geoelectric fields at Earth's surface → generates → GICs on long conductors

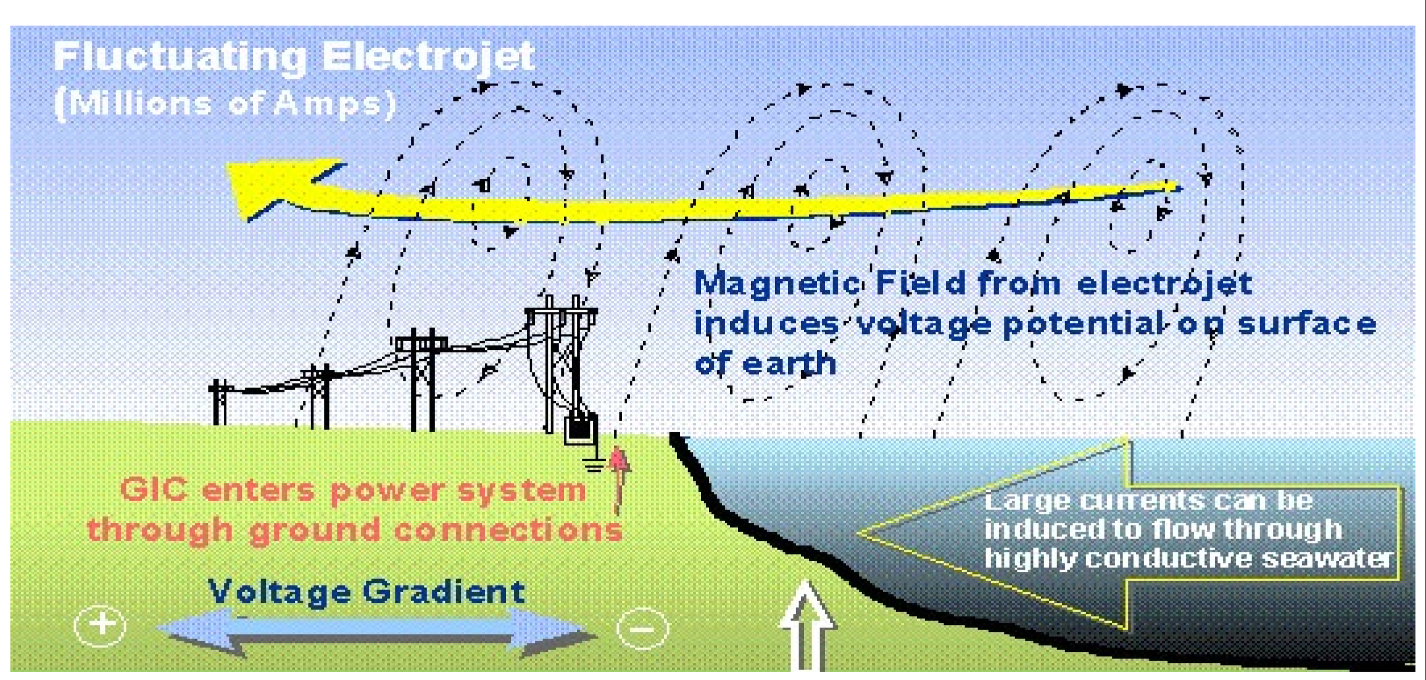
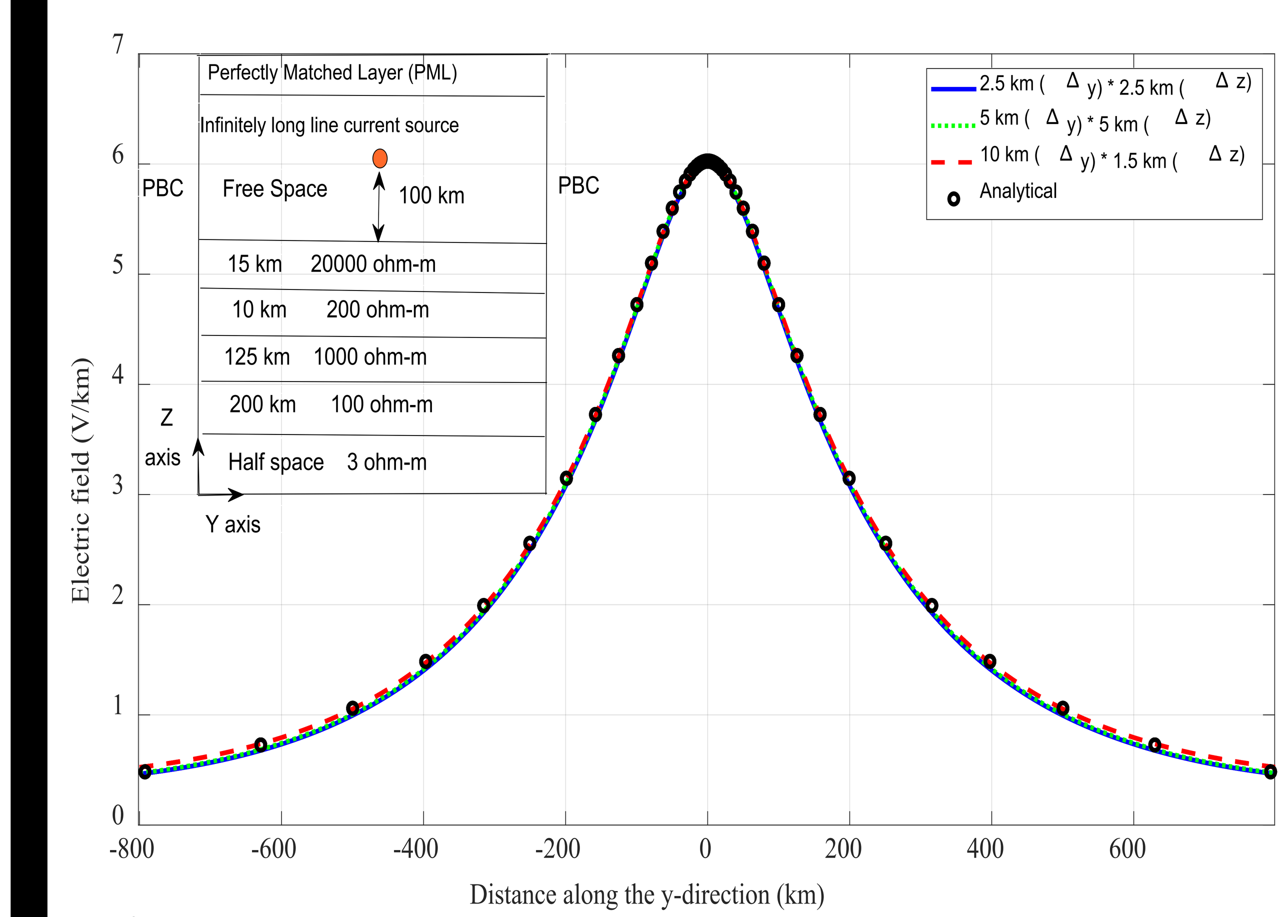


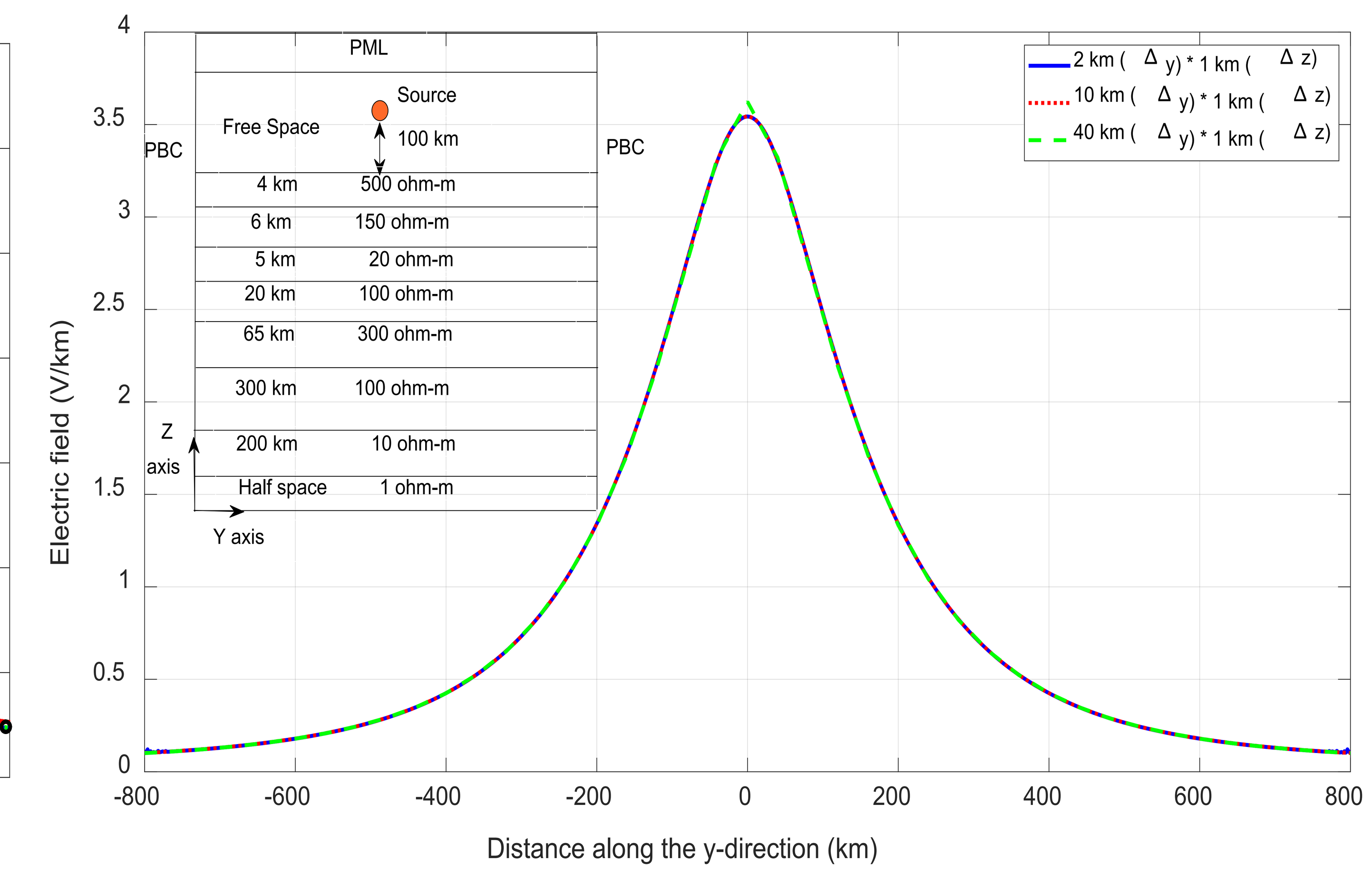
Fig: Physics at ocean-continent interface

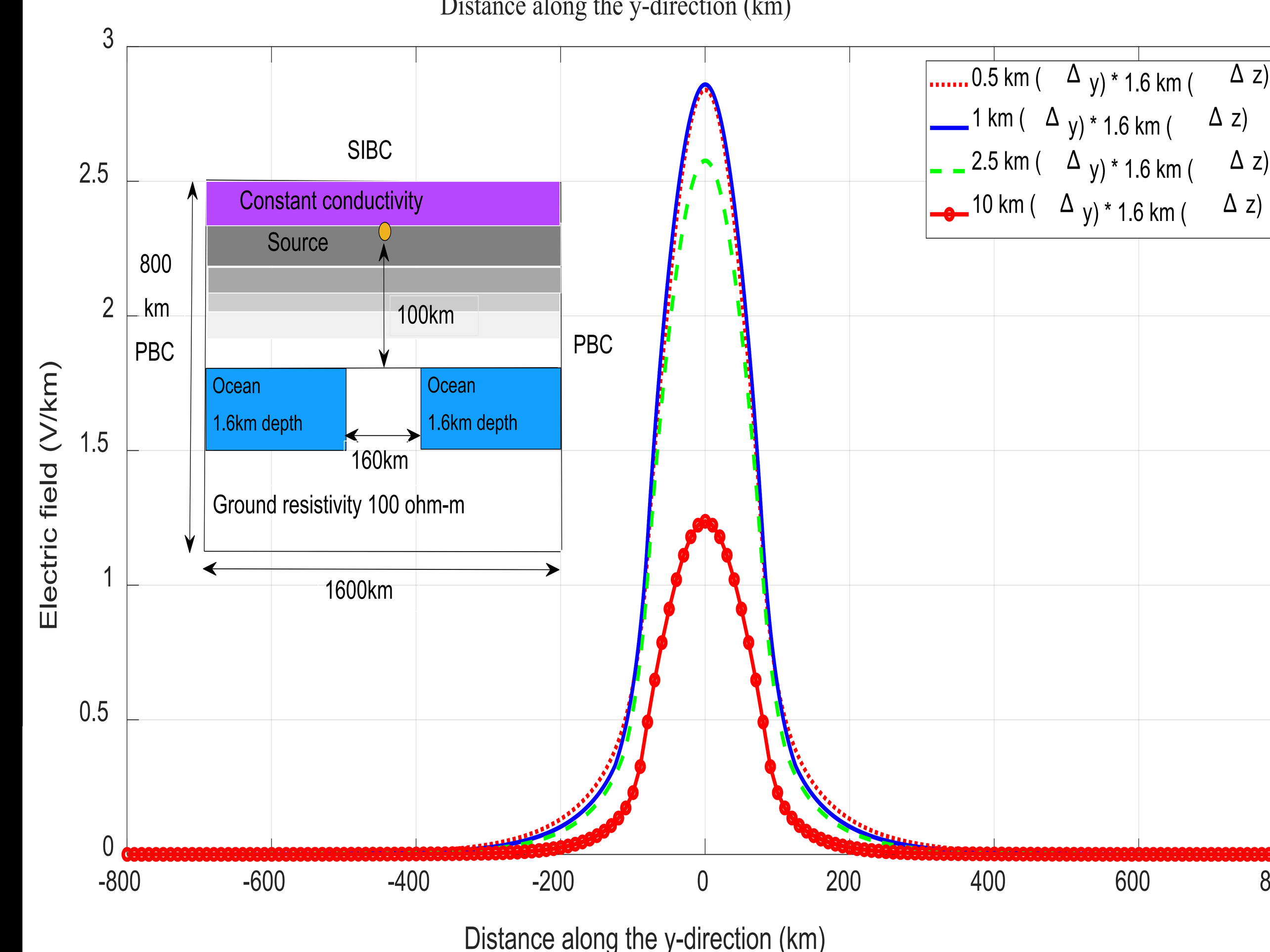
Conclusions

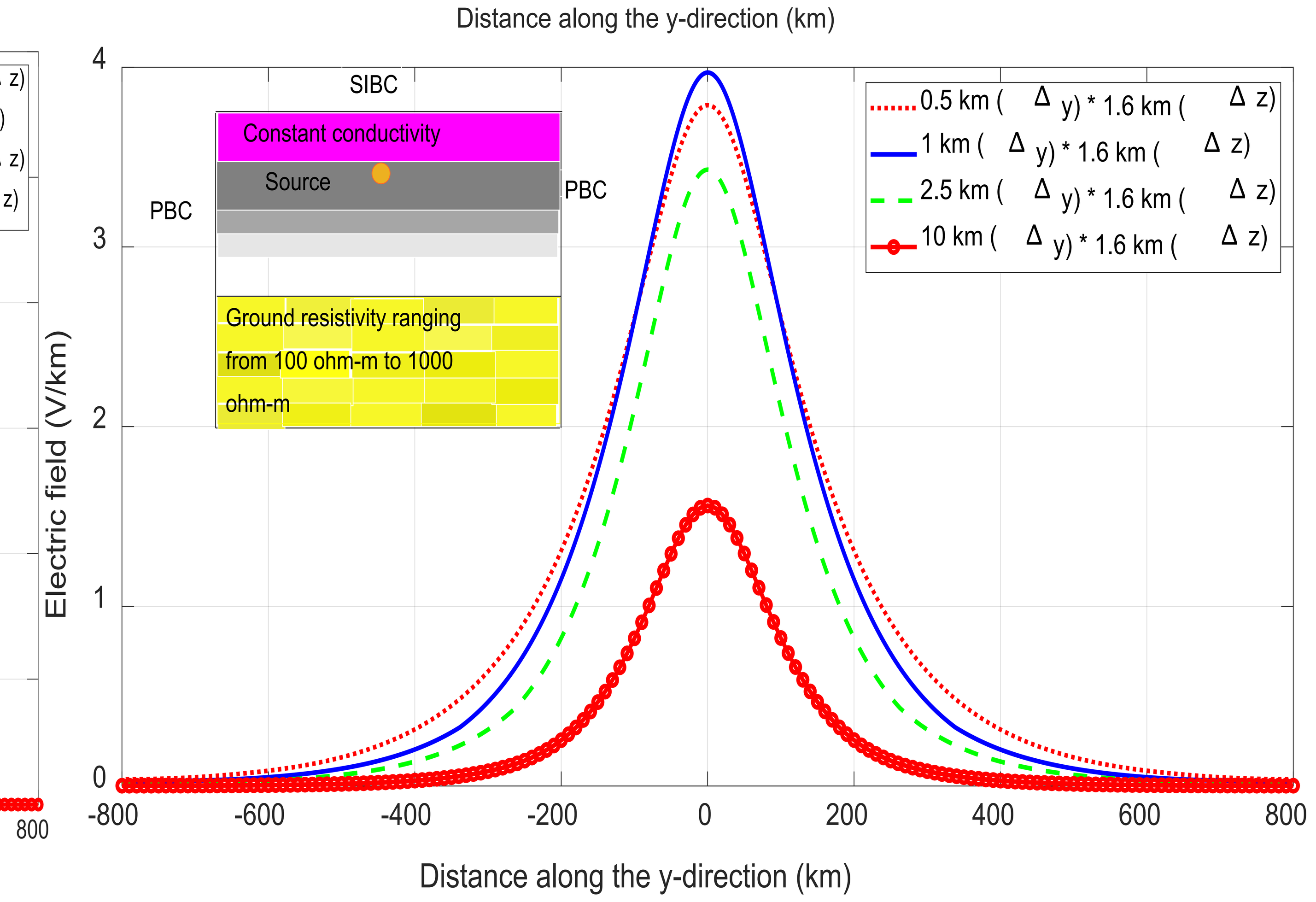
- Whenever the ground composition varies in the horizontal direction, then the horizontal (not just the vertical) grid resolution of the FDTD model must be < 1/3 of a skin depth. This is necessary because the electromagnetic waves propagating from the disturbed ionospheric currents are not true plane waves; the ground is in the near field of the ionospheric current sources.
- When variations in the ground structure are included (such as those predicted by regional and global ground models, e.g., [3]) the resolution of the FDTD models should be at least three times higher than the ground model resolutions. This allows the FDTD models to more accurately account for the diffraction of electromagnetic waves around the ground structures in the near field of the ionospheric sources.

Results: Geoelectric fields for Different Ground Scenarios and Grid Resolutions









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