ADAPTIVE MESH REFINEMENT FOR RADAR SOUNDER DATA SIMULATION WITH A 3-D FINITE DIFFERENCE TIME-DOMAIN TECHNIQUE

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INTRODUCTION

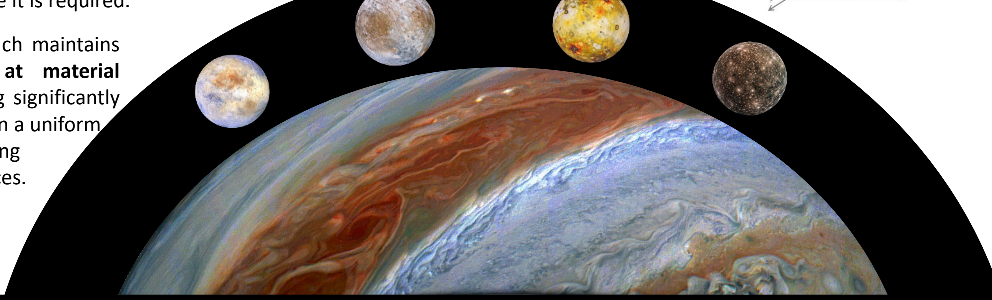
- **Radar Sounders (RS)** are nadir-looking active sensors designed to probe subsurface structures on planetary bodies.
- **RS data simulation** is essential for interpreting complex echoes, evaluating instrument performance, and inverting target properties from backscattered signals.
- **Optical ray-tracing**[1] is computationally effective but cannot model full wave effects over rough and complex terrain.
- **Numerical methods** such as FDTD[2] capture full wave physics accurately but demand very high computational resources and are sensitive to numerical dispersion.

Research Gaps

- **Uniform fine grids** make large-scale RS simulations impractical.
- **Coarse grids** cause numerical instability and can produce staircasing error.

Solution

- We propose a novel hybrid framework integrating **adaptive mesh refinement (AMR)**[3] with a **3-D FDTD** to target mesh refinement only where it is required.
- The proposed approach maintains **full-wave accuracy at material interfaces** while using significantly fewer grids points than a uniform fine mesh**,** thus reducing computational resources.



METHODOLOGY

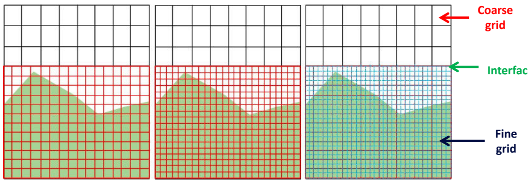
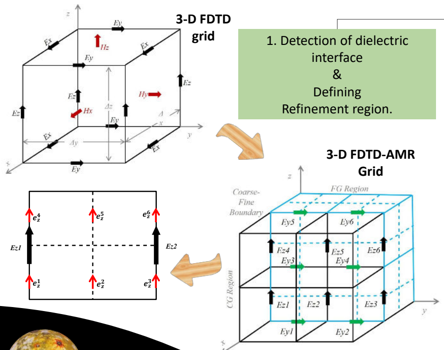
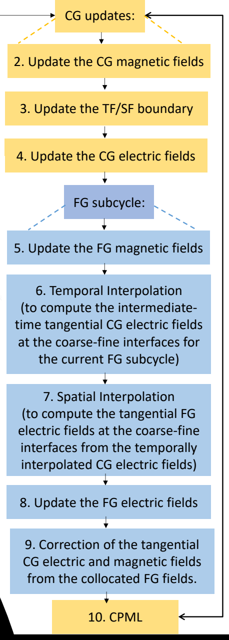


Fig. 1. (a) Refinement ratio 2, (b) Refinement ratio 3, and (c) Refinement ratio 2 and level 2





1. Detection of dielectric interface & Defining Refinement region.

CG updates:

2. Update the CG magnetic fields
3. Update the TF/SF boundary
4. Update the CG electric fields

FG subcycle:

5. Update the FG magnetic fields
6. Temporal Interpolation (to compute the intermediate-time tangential CG electric fields at the coarse-fine interfaces for the current FG subcycle)
7. Spatial Interpolation (to compute the tangential FG electric fields at the coarse-fine interfaces from the temporally interpolated CG electric fields)
8. Update the FG electric fields
9. Correction of the tangential CG electric and magnetic fields from the collocated FG fields.
10. CPML

RESULTS

2-D case:

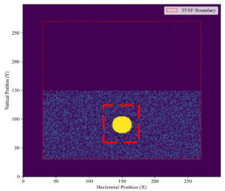


Fig. 2. 2-D Simulation setup of buried scatterer (ε_r=5) in a random dielectric surface.

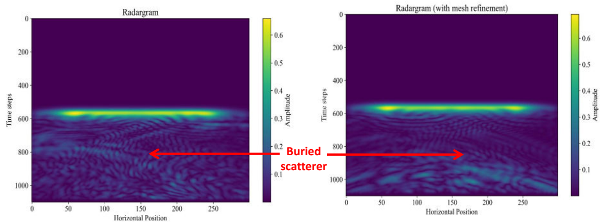


Fig. 3. 2-D Simulated Radargram of a buried dielectric scatterer in a random dielectric surface (a) without AMR, and (b) with AMR.

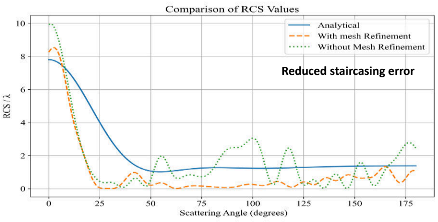
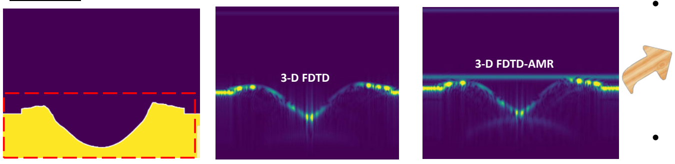


Fig. 4. Normalized RCS of a PEC circular cylinder (2-D scenario)

3-D case:



Simulation	Grid cells	Time-steps	Total updates
Uniform (dx =1.5 m)	1000 x 200 x 4000	6000	**4,800,000 M**
AMR-FDTD (dx = 3m—1.5m for dielectric layer)	500 x 100 x 2000 (global) 298 x 108 x 3908 (refined layer)	3000 (global) 6000 (refined layer)	**1,055,000 M**

- In this case AMR provides a 4.5× reduction in total updates relative to a uniform grids.
- This approach has also been applied to a realistic scenario using MOLA DEM data of Mars, enabling large-scale simulations while maintaining numerical stability and avoiding spurious artifacts.

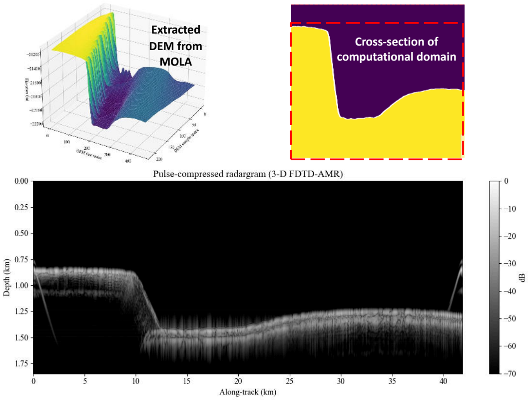


Fig. 5. Range compressed Radargram (3-D FDTD-AMR)

REFERENCES

1. Gerekos, C., Tamponi, A., Carrer, L., Castelletti, D., Santoni, M., & Bruzzone, L. (2018). A coherent multilayer simulator of radargrams acquired by radar sounder instruments. IEEE Transactions on Geoscience and Remote Sensing, 56(12), 7388 7404.

2. Sbalchiero, E., Cortellazzi, M., Thakur, S., & Bruzzone, L. (2023). A Dictionary-Based Integrated Simulation Approach to Model Large- and Small-Scale Coherent Surface Scattering Phenomena in Radar Sounder Data. IEEE Transactions on Geoscience and Remote Sensing, 61.

3. Balsara, D. S., & Sarris, C. D. (2023). A Systematic Approach to Adaptive Mesh Refinement for Computational Electrodynamics. IEEE Journal on Multiscale and Multiphysics Computational Techniques, 8, 82–96.