Robust Spectral-Domain Methodology for Numerical Modeling of Remote Sensors: Application to CSEM Prospection of Marine Hydrocarbon Reserves

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Summary: We present a *robustly* (i.e., to sensor and environment properties) numerically-stable, accurate, and rapid spectral-domain computational algorithm possessing two capabilities important for the modeling of remote sensors routinely employed in Controlled Source EM (CSEM)-based prospection of marine hydrocarbon reserves. Specifically, in addition to addressing well-known issues in the spectral-domain computation of fields radiated in planar-layered media, our algorithm solves a challenge that arises when desiring the *scattered* fields radiated by *distributed* (rather than Hertzian/point-like) sources. Solving this challenge plays an important role in efficiently evaluating the performance more realistically-modeled sensors, including the sensitivity of their vector measurements to the presence of hydrocarbon reserves. Numerical tests indicate that once these challenges are solved, a one or two order of magnitude compute speed increase (for wire and aperture sources, resp.), with typically ten or more digits of accuracy, can be realized via said direct spectral-domain computation approach. We present numerical CSEM-based hydrocarbon prospection results, understanding how ocean water depth affects seafloor measurement sensitivity to the reservoir's presence.

Background: CSEM is an active-illuminator geophysical exploration method for the surveying of marine hydrocarbon reserves. The typical illuminator consists of a wire antenna emitting low-frequency tones (~0.01Hz-10Hz) to achieve deep EM wave penetration through conductive ocean waters and (in general anisotropic) marine sand and rock layers. This prospection method has received increasing attention in recent years due to its ability to detect and image reservoirs of hydrocarbons deeply buried under the seafloor, as initially demonstrated during a field campaign off Angola's shore. There is hence growing interest in numerically modeling different remote sensor geometry and placement strategies to increase the payoff (reservoir productivity) of more invasive exploration operations (i.e., drilling).

Challenges: Significant challenges remain in robust, high-fidelity CSEM computational modeling scenarios when sources are embedded in planar-layered media of general thickness and material characteristics. Among more traditional challenges when performing a spectral-domain evaluation of the EM field, one can cite highly oscillatory and slowly decaying integrands which can lead to poor accuracy, poor numerical convergence, and high compute cost/time. Moreover, quite challenging is the numerical evaluation of the *scattered* EM field due to *distributed* radiators (e.g., CSEM wire antennas). Indeed, the modeling task is hampered by the presence of exponentially rising terms (ERT). If these ERT are not analytically treated carefully prior to numerical evaluation of the spectral-domain field expressions, the ERT can engender grossly inaccurate or even numerically overflown results.

Solution and Application: In the presentation, we explain the origination of these ERT, how to robustly suppress their ill behavior by analytically combining them with the exponentially decaying terms associated with single Hertzian dipole field calculations, and applying the distributed-source scattered-field algorithm to understanding sensitivity trends concerning sensors used in CSEM-based marine hydrocarbon exploration.