Characterization of super-low frequency electromagnetic fields produced by an undersea transmission cable in a homogeneous fluid

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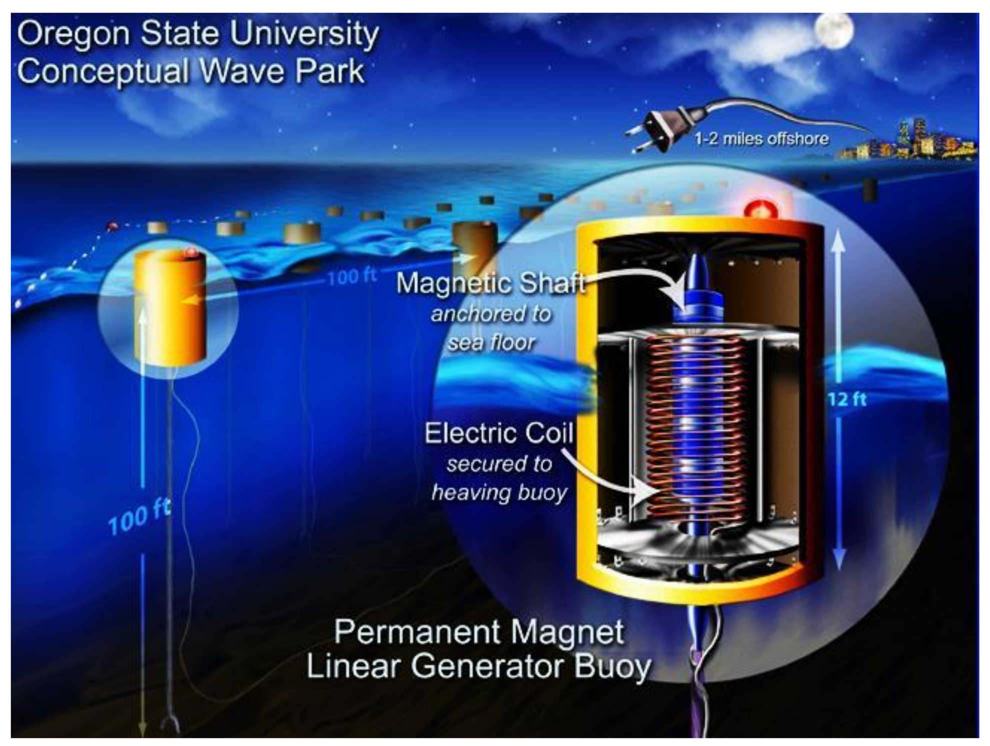
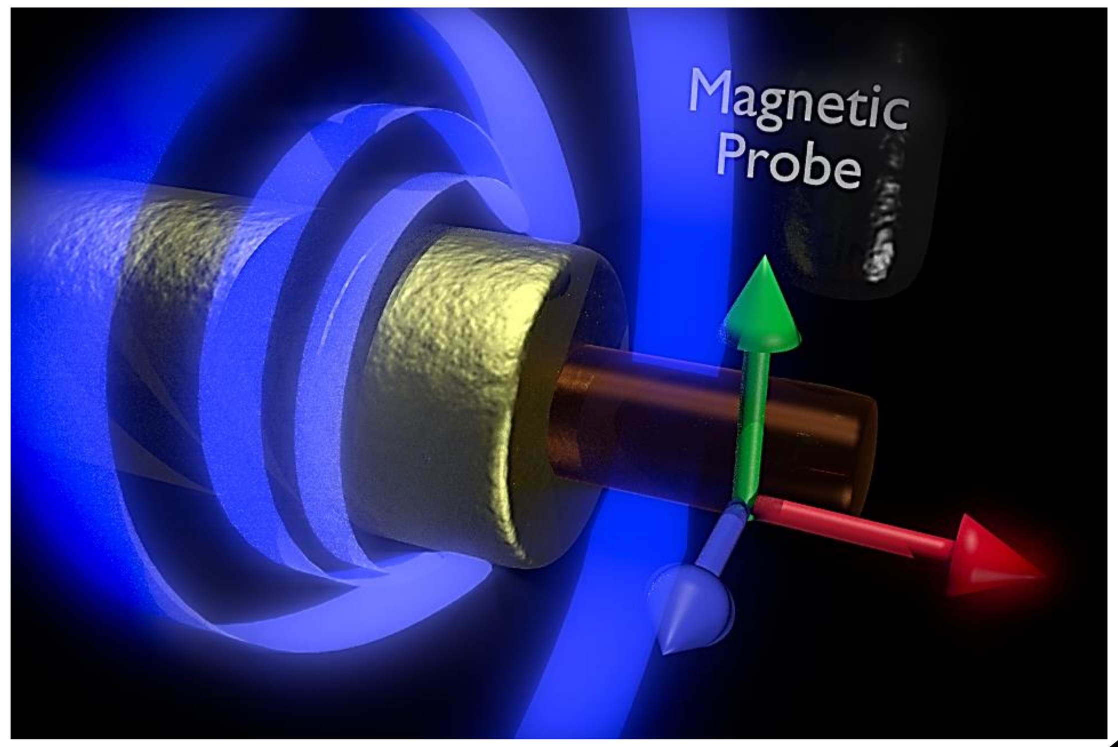
WAVE ENERGY AND THE POTENTIAL ENVIRONMENTAL IMPACTS

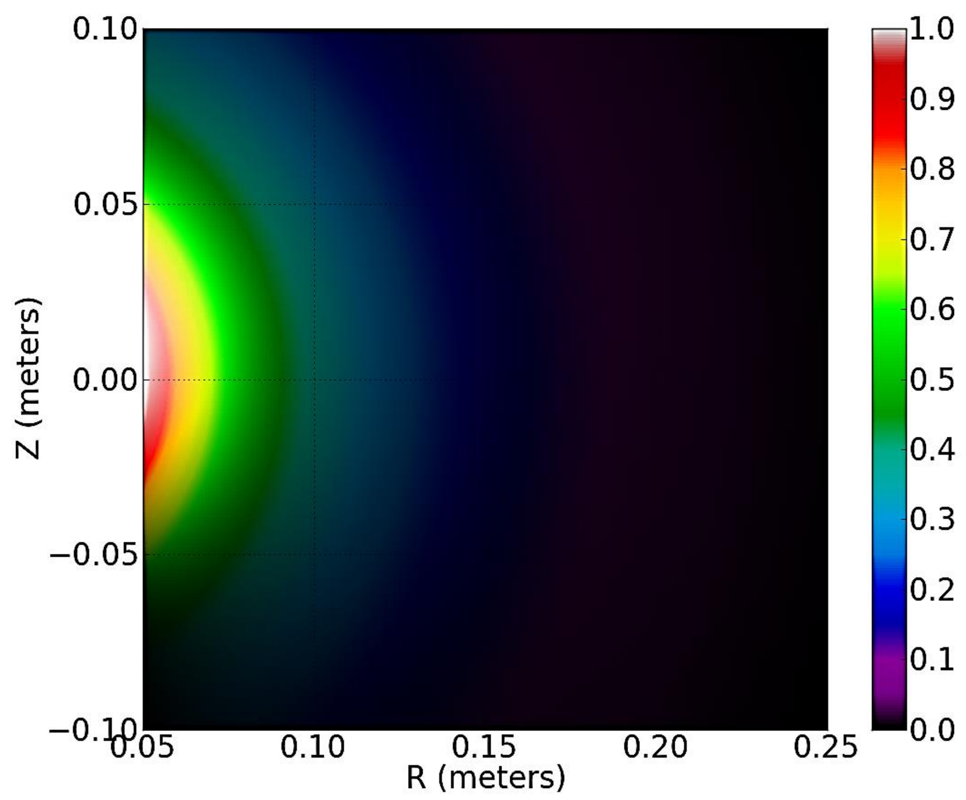
Clean, Renewable Wave Energy: Offshore renewable energy is an untapped resource in the United States, and has the potential not only to add to our clean energy mix, but to create jobs as well. The National Renewable Energy Laboratory estimates that the United States could harvest 54 gigawatts (GW) from offshore wind by 2030 -- enough to power more than 42 million homes. This would generate an estimated $200 billion in new economic activity and create more than 43,000 permanent, well-paid jobs.

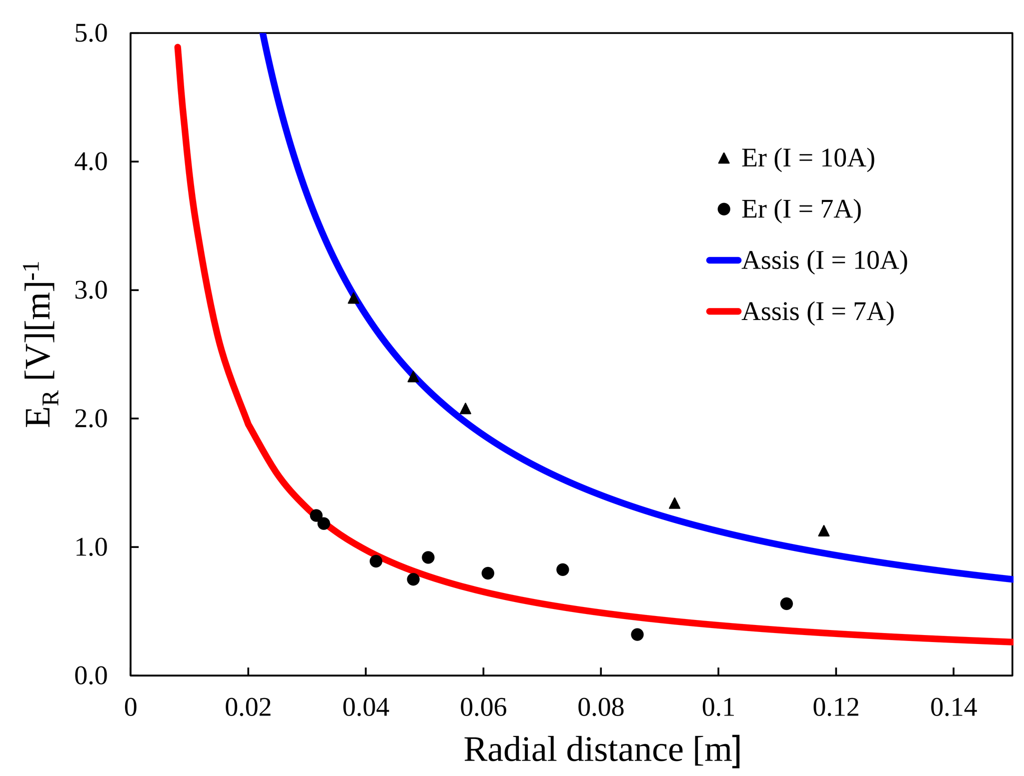
Environmental Issues: There are a number of high priority issues including those that deal with potential impacts on marine mammals and seabirds, the effects on the physical environment, and changes to the (ocean floor) habitat. For fish and mammalian species, sensory perception, migration, orientation, and even entanglement can be caused by perturbations in the electric and magnetic fields.





MAXWELL'S EQUATIONS TO CALCULATE B_φ and E_R





$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} \qquad \frac{B_\varphi}{I} = e^{i\omega t}\frac{\mu_0}{2\pi R}$$

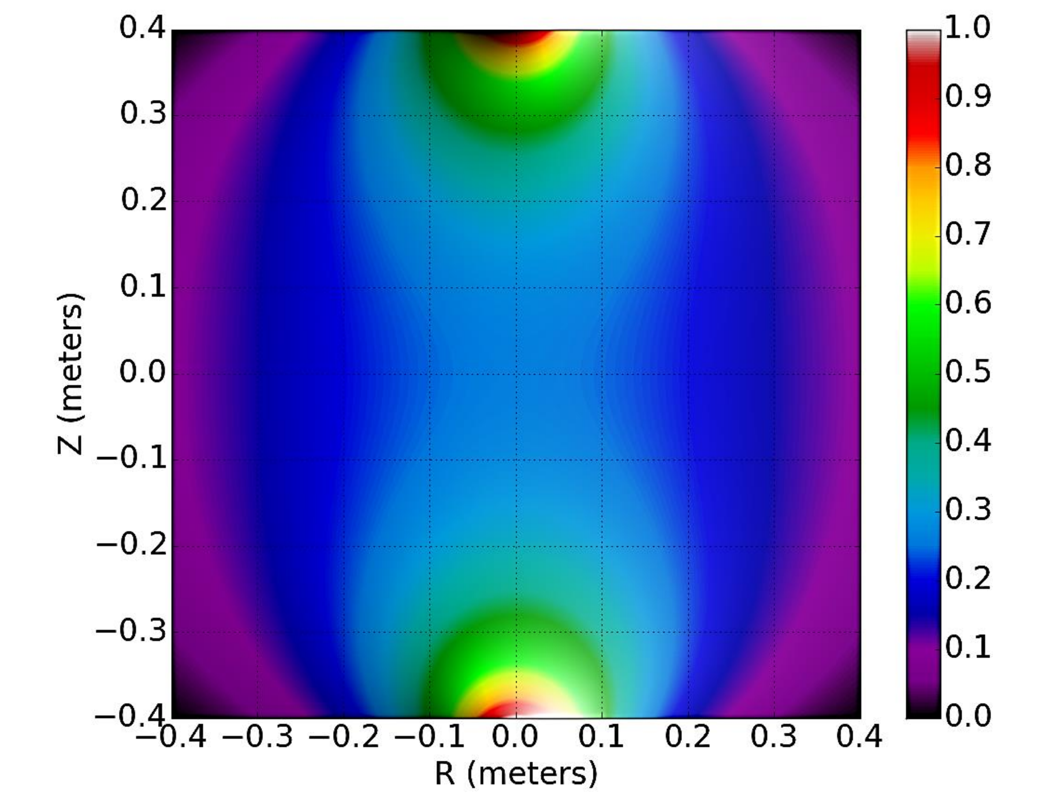
$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \qquad \frac{E_R}{I} = \frac{L/\sigma\pi a^2}{2R\ln(L/a)}$$

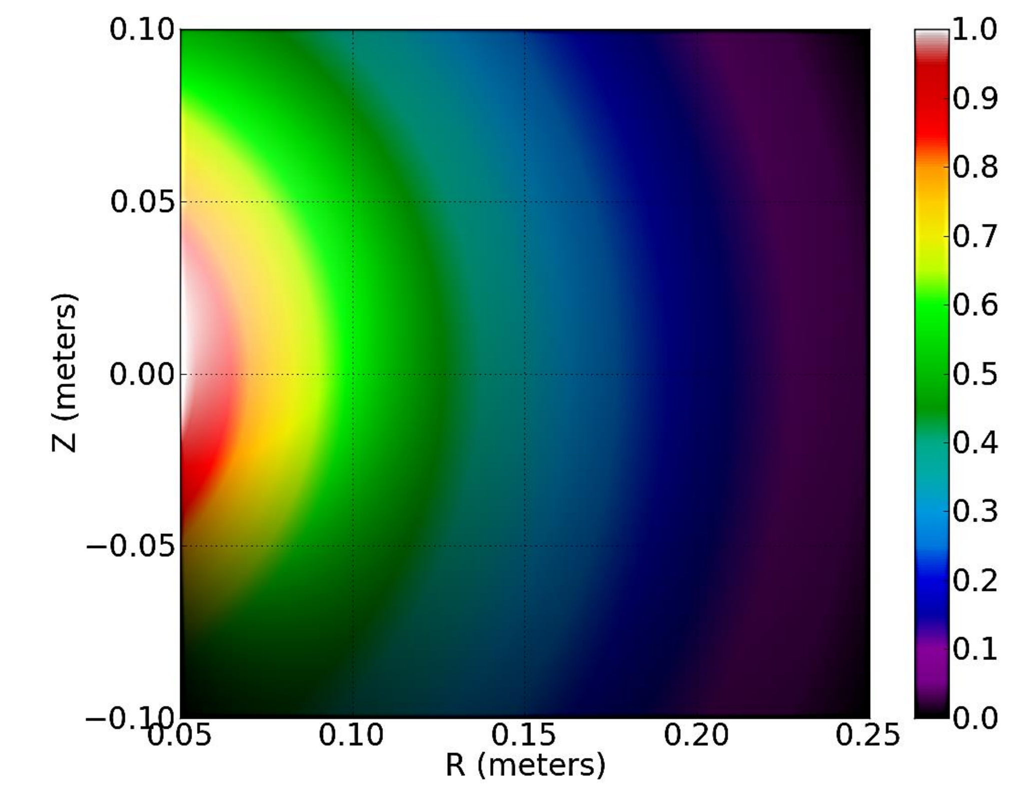
Maxwell's Equations: The fundamental set of electromagnetic equations can be used to calculate the angular magnetic field component and the radial electric field component. The excellent correlation between theoretical and experimental measurements is independent of the homogenous medium i.e. the result is the same for both air and synthetic seawater.

THE HERTZ VECTOR TO CALCULATE THE INDUCED ELECTRIC FIELD

Sommerfeld, Stratton, Wait, and Inan: While Maxwell's equations can be represented using both vector and scalar potentials, these two methods of representing Maxwell's equations are not the only possible choice. By introducing a more regular 'superpotential' called the Hertz vector potential or polarization potential, the points of discontinuity are placed away from the measurement point; thus allowing for a continuous prediction of the field strength.

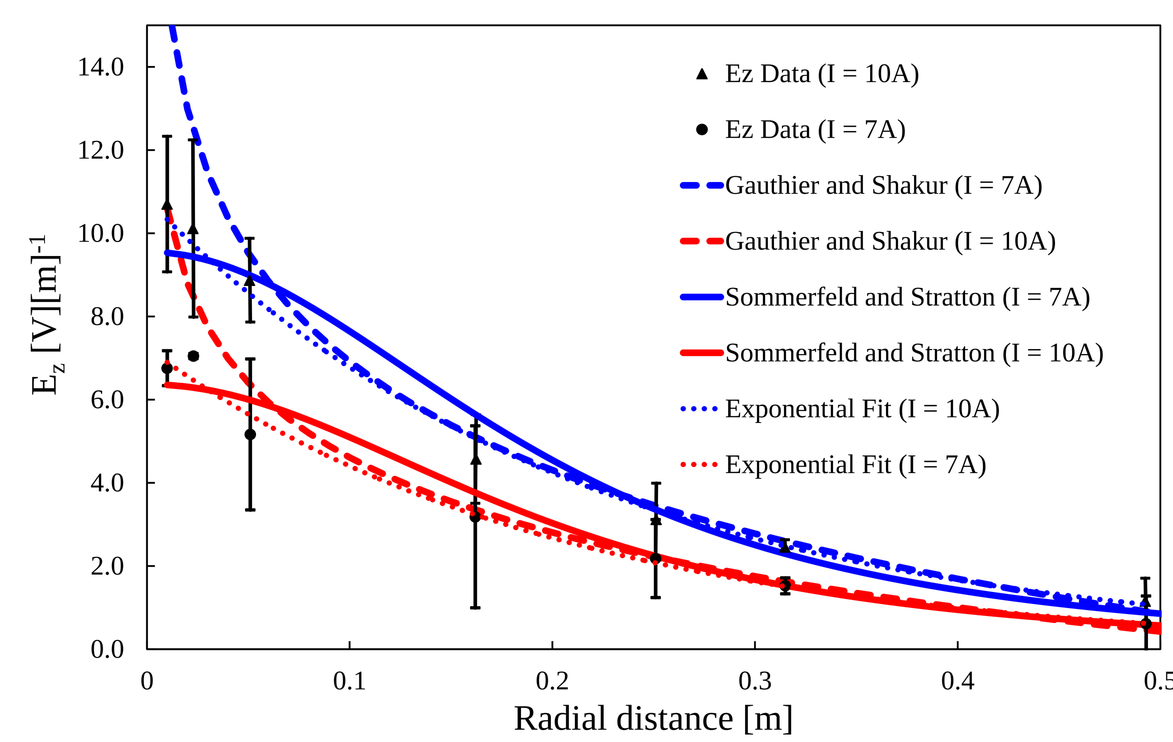
Gauthier, Shakur, Heald, and Griffiths: Maxwell's equations can explicitly be solved in terms of the electric field **E** and the magnetic field **B**. The method that was brought up in 1985 by Shakur and discussed by Gauthier treats the problem using **E** and **B** directly. Heald suggested that the global geometry of the problem needs to consider the energy sources in the system in order to account for the diverging logarithm. Griffiths added that the constant K depends on the history of the current in the conductor.

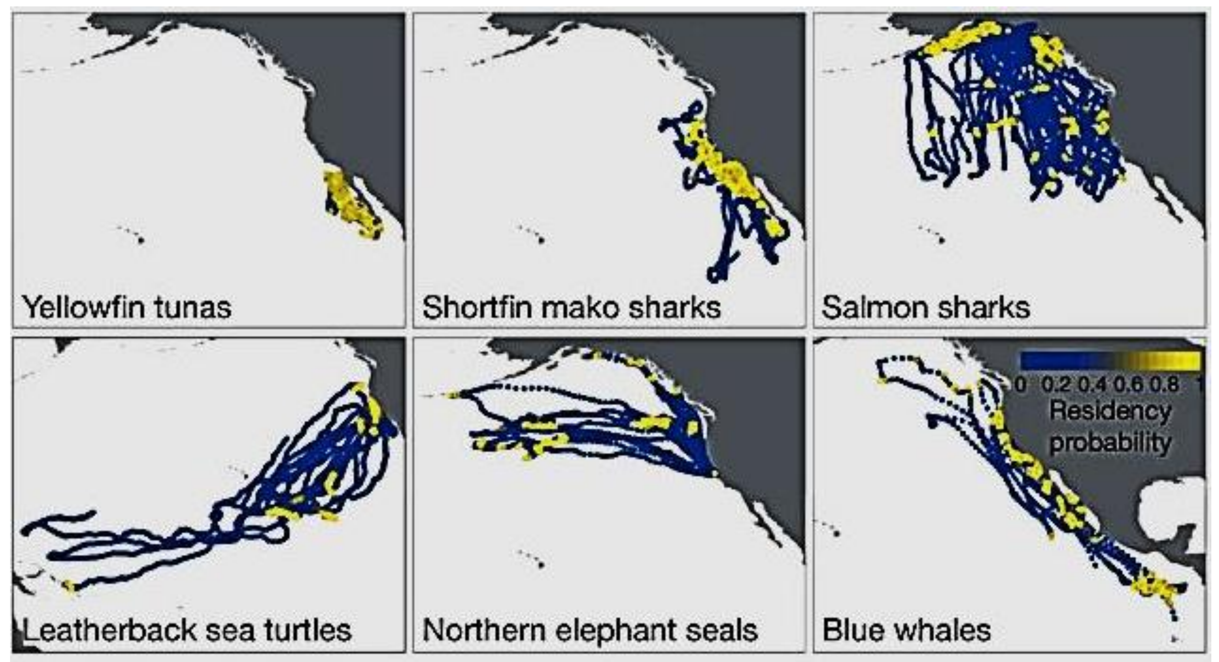




$$\frac{E_z}{I} = \frac{i\mu\omega}{4\pi}\left[\sinh^{-1}\left(\frac{\ell_2 - z}{\rho}\right) - \sinh^{-1}\left(\frac{\ell_1 - z}{\rho}\right)\right] + \frac{z-\ell_1}{4\pi\sigma r_1^3} - \frac{z-\ell_2}{4\pi\sigma r_2^3}$$

$$\frac{E_z}{I} = -i\omega e^{i\omega t}\frac{\mu}{2\pi}\ln\left(\frac{R}{a}\right) + K$$





Large Marine Predator Migratory Map

Potential Impacts on Marine Life: The impacts on marine life can vary depending on the organism and the strength of the field. Certain planktonic organisms such as *Daphnia* give off static or quasi-static electric fields. These fields can be dwarfed by larger fields created by underwater sea cables; thus inhibiting many different types of fish that rely on electromagnetic detection including the paddlefish *Polyodon spathula*. Also sharks and rays are particularly adept at detecting small electrical signals and research suggests that this is their primary method of detection of prey. Low frequency electric fields have been found to be more easily detected by electro-sensitive species. Magneto-sensitive species may also be impacted by the magnetic field from the underwater sea cable. More than 45 different species, including 5 mammalian species, have been shown to make use of an internal magnetic compass. Through electromagnetic emission, underwater sea cables have the potential to impact a variety of marine life.

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