SCUBAS: A python-based numerical model to estimate electrical surges in submarine cables during geomagnetic disturbances

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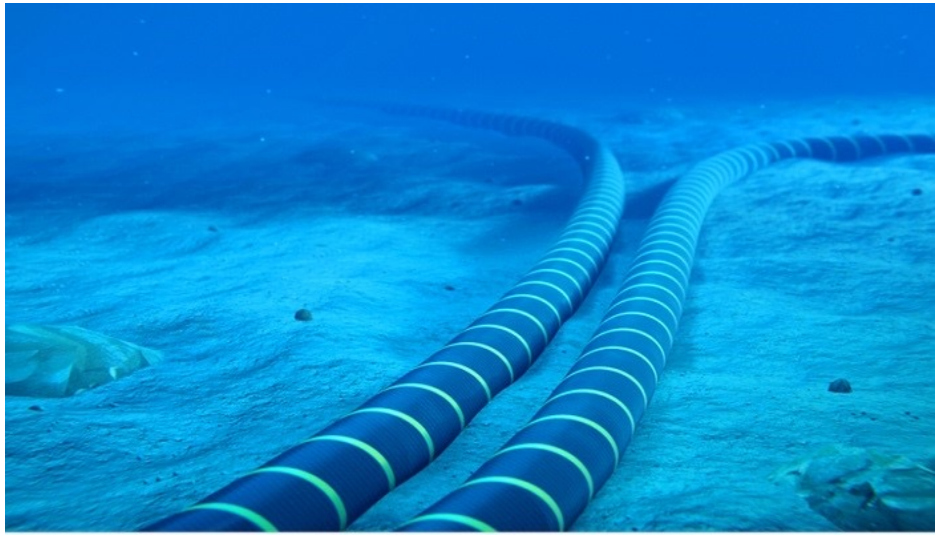
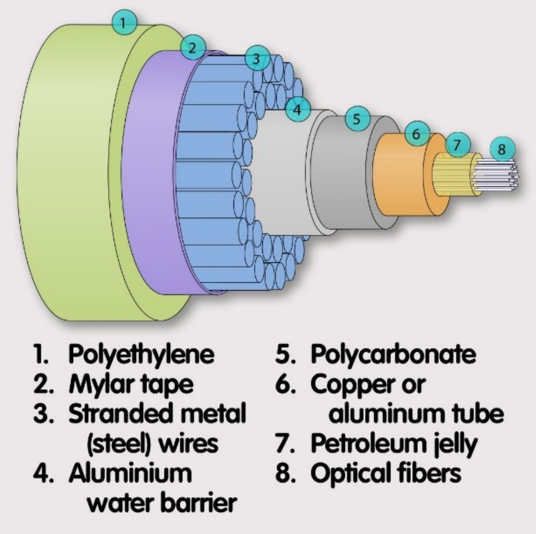
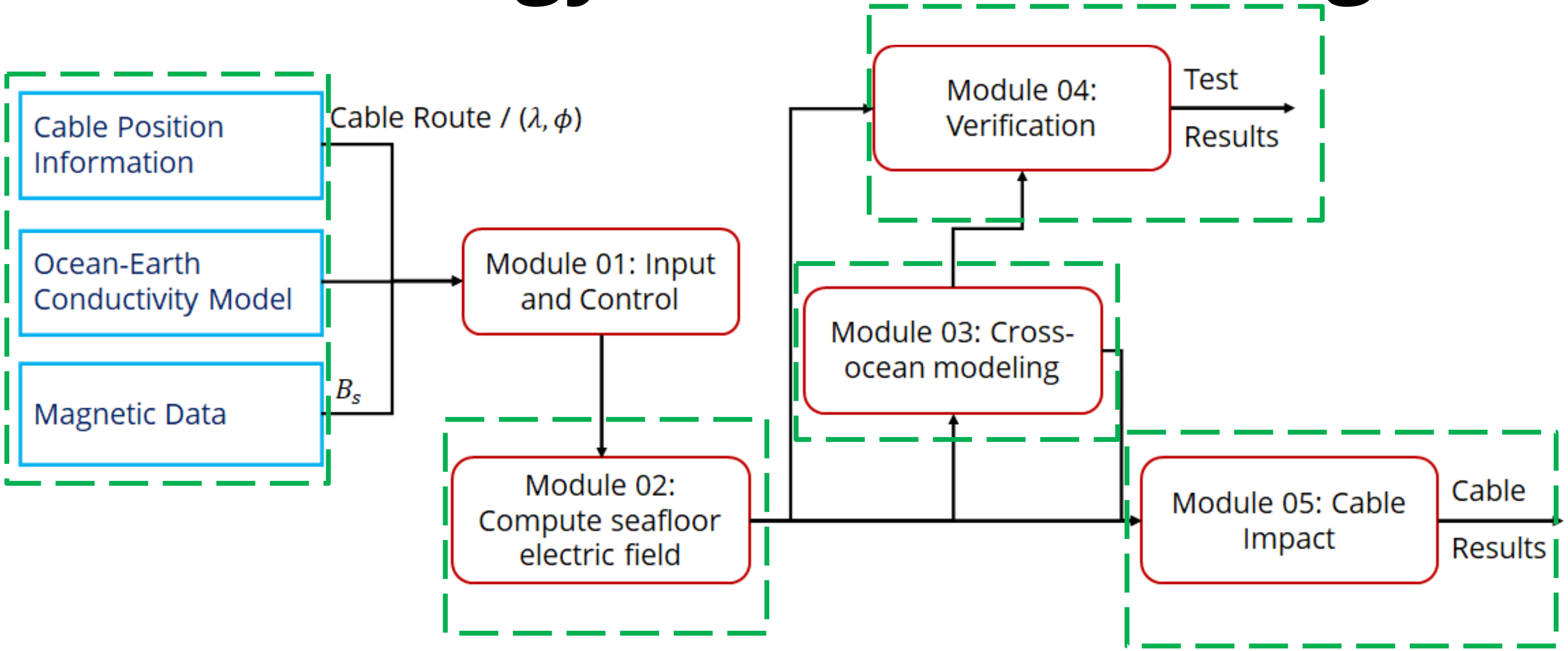
Introduction: Risk to Submarine Cables

- A submarine communications cable **(SCC)**, a cable laid on the sea-bed to carry telecommunication signals across stretches of ocean and sea.
- Previously, copper wires / coaxial cables used, but since 90s, they are being replaced by optical fibers.
- Impacted / damaged by natural hazards such as submarine landslides and tsunami.
- Recently, there is increased concern about Space weather effects (High Impact, Low Frequency (HILF) events).
- **<u>Objective</u>**: Build a model for risk assessment of extreme geomagnetic storm-driven interruptions to cable operations and instruments along the SCC.





Methodology: Model Flow Diagram



- Model can digest cable position, magnetic data, and ocean-earth conductivity model
- Compute transfer function (T_x) that relates, seafloor electric field (E_f) to surface magnetic field (B_s)
- Compute E_f using T_x and B_s for each cable section
- Combine the effect of different cable sections to get total effect on cable
- We validate the model outputs against a few analytic solution using synthetic magnetic field data, pre-defined transfer functions T_x, and cable geometry.

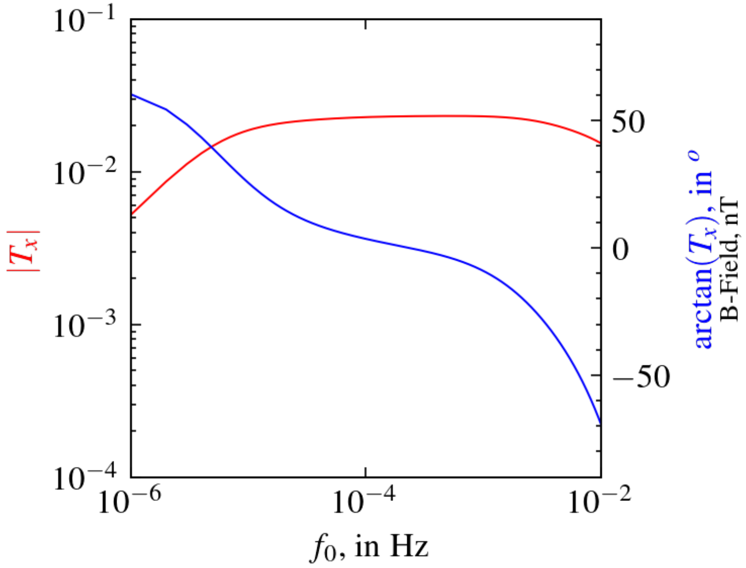
Python-based implementation

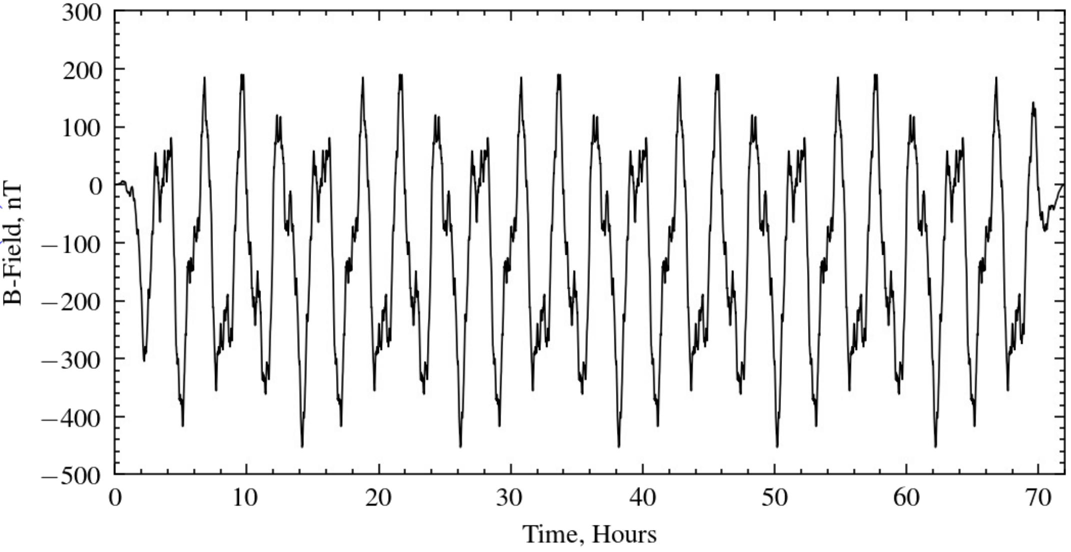
Documentation

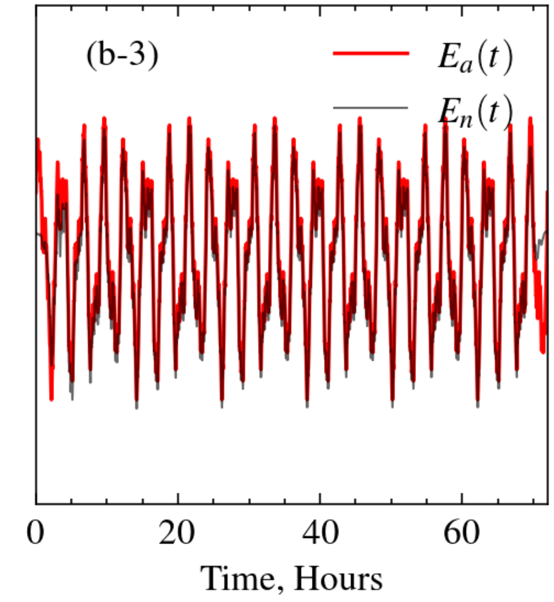
GitHub

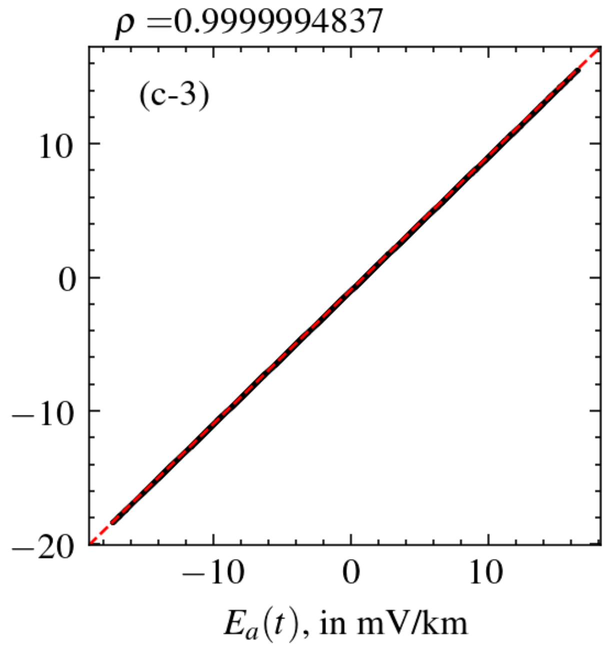
- Documentation of the model is available in readthedocs.io.
- The library source code can be found on the SCUBAS GitHub repository.
- Installer *pip, pip3*.

Case Study: Synthetic B_s and T_x



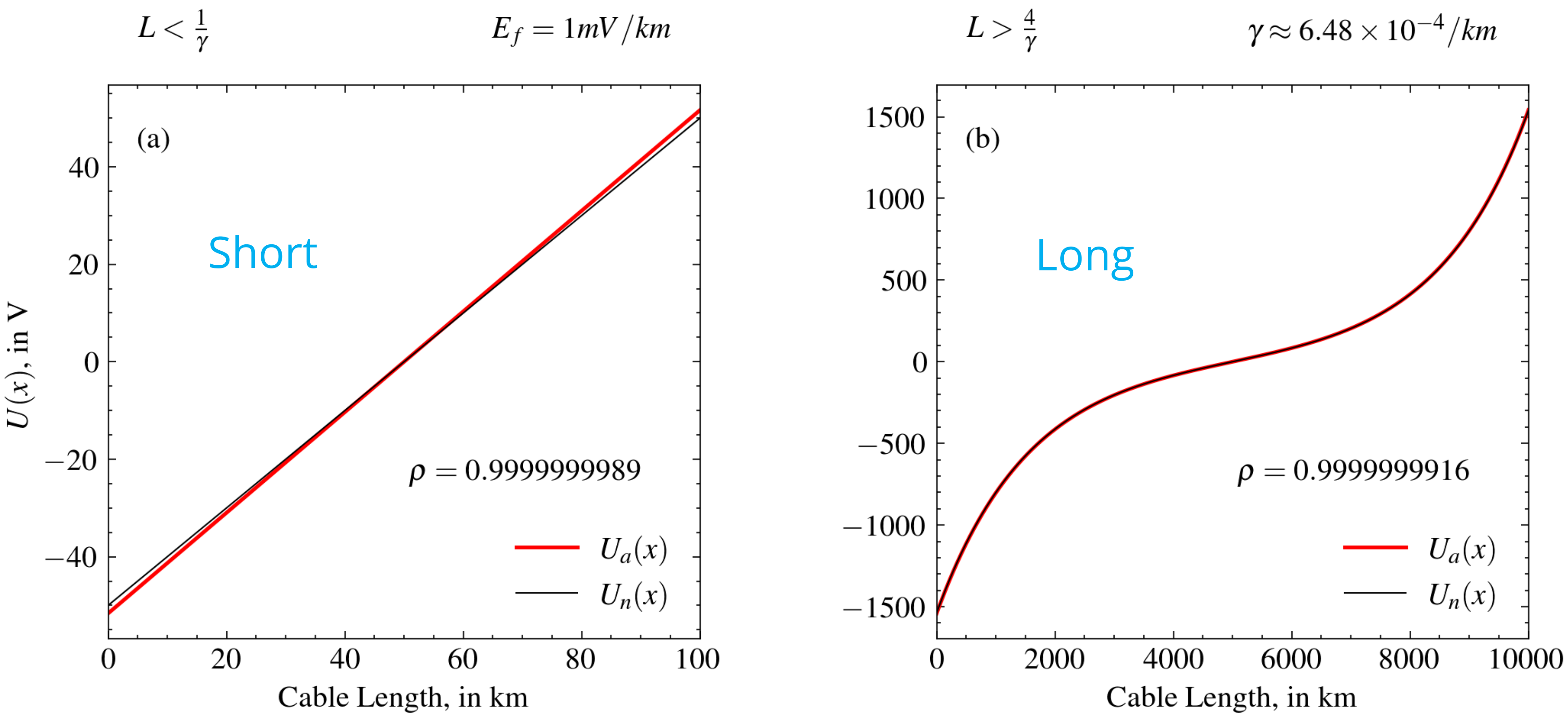






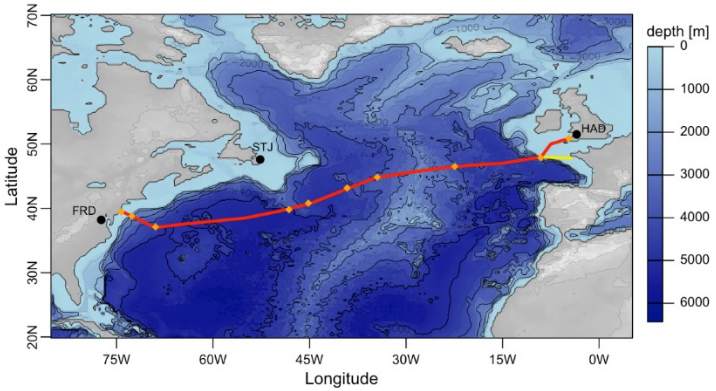
- Synthetic magnetic data: $B_s = \sum_{i=1}^{6} A^{(m)} \sin\left(2\pi f^{(m)} t + \phi^{(m)}\right)$, m frequency components.
- Analytical solution: $\mathrm{E_a(t)} = \sum_{i=1}^{6} |T_x|^{(m)} A^{(m)} \sin\left(2\pi f^{(m)} t + \phi^{(m)} + \theta^{(m)}\right)$
- Numerical estimate: $\mathrm{E_n(t)} = ifft(B_s[f] \times T_x[f])$
- Correlation analysis suggest (ρ) that model (black curves) is able to replicate analytical solution (red curves) with high confidence.

Case Study: Electrically Short and Long Cables

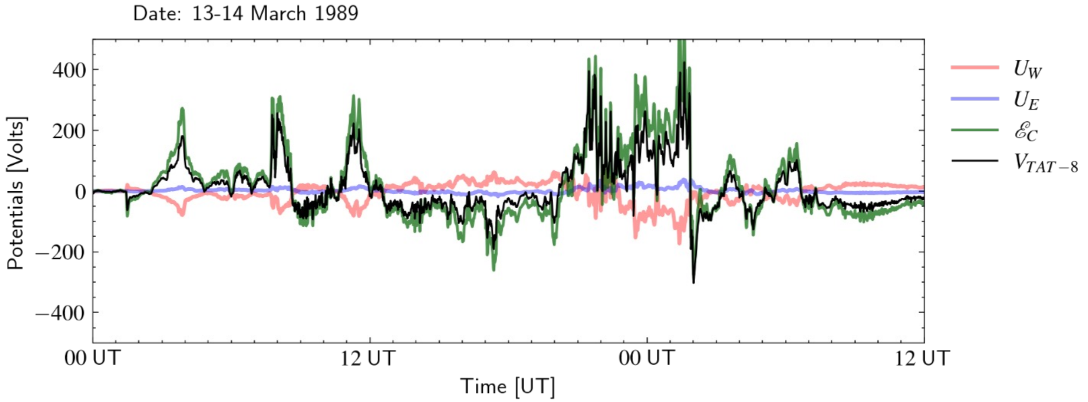


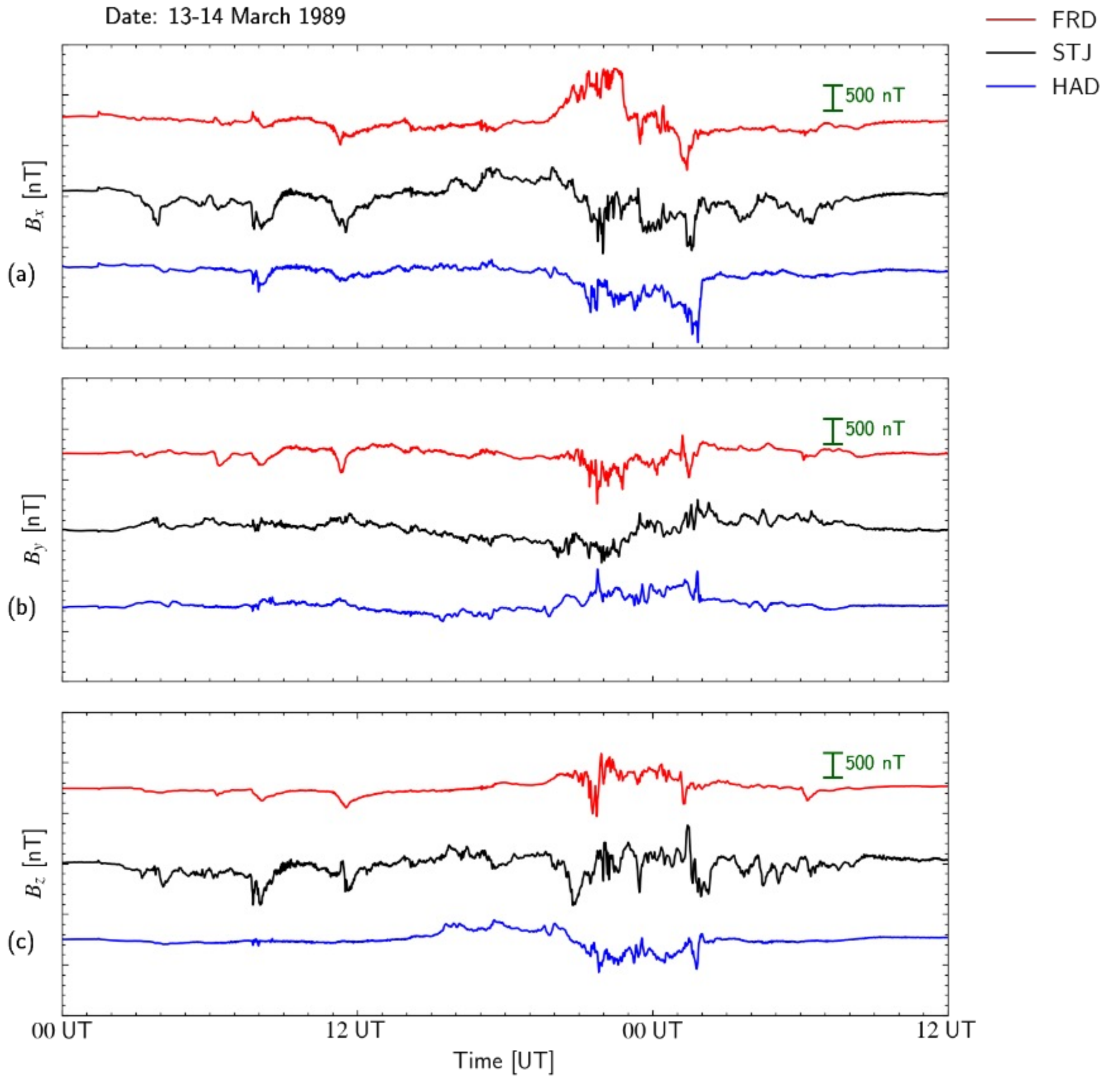
- Same T_x used for previous case study.
- We synthetically feed an induced electric field $E_f = 1\,mv/km$, to an electrically short (left panel, 100km) and long (right panel, 10000 km).

Testing the model on a real event: March 1989



"EVENT"	Δτ, min	Measured PFE VOLTAGE EXCURSION (V)	Modeled cable voltage variation (V)
SSC, 01.30 UT, March 13	~ 2	~ 75	63
11.10 UT, March 13	~ 25	~ 300	223
21.45 UT, March 13	~ 6	~ 450	383
01.30 UT, March 14	~ 25	~ 700	727





Conclusions, Future work, and Open Questions

- We developed a model framework to estimate geomagnetic induction effect on the submarine cables.
- The model is available in **GitHub**, model is published, you can '**pip install scubas**'.

- **Future Extension (Science)**:
  1. Risk Assessment: How vulnerable are submarine cables during Carrington-type events? Is there any chance to observe an '*internet apocalypse*' (i.e., global loss of internet coverage, https://www.livescience.com/solar-storm-internet-apocalypse)?
  2. Uncertainty Quantification: Quantify uncertainty in the calculated voltage / electric field.
  3. Nowcasting: Provide real time update on induced electric field and potential along the submarine cables.

Thank you!

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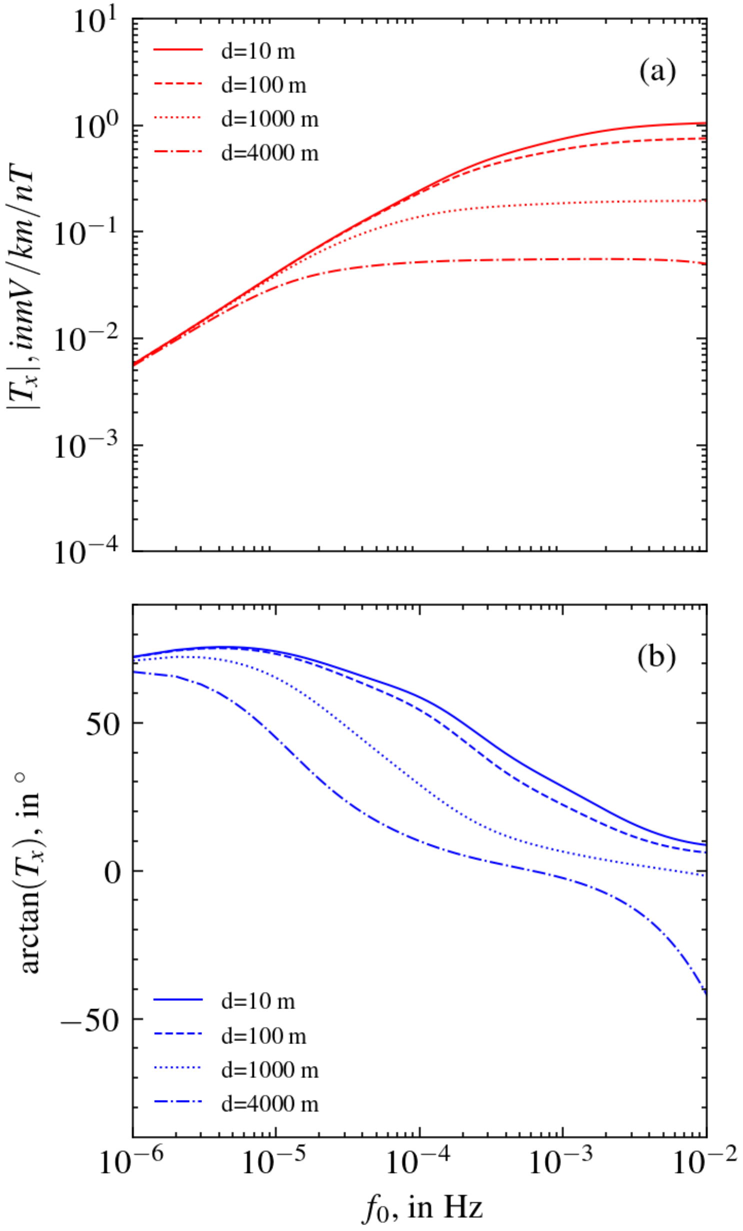
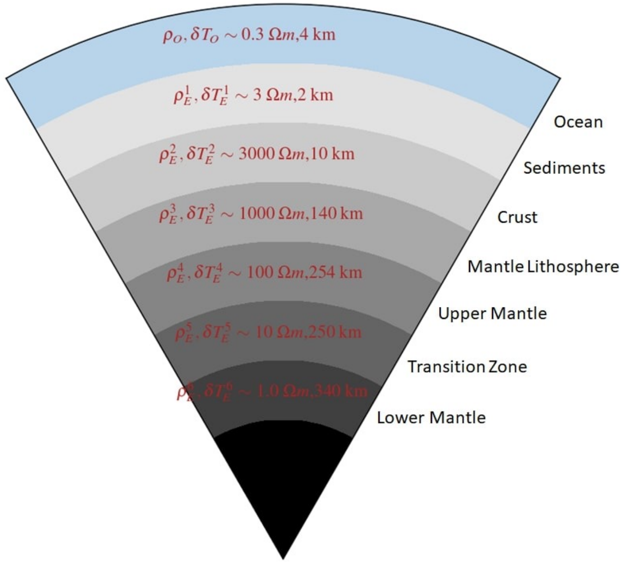
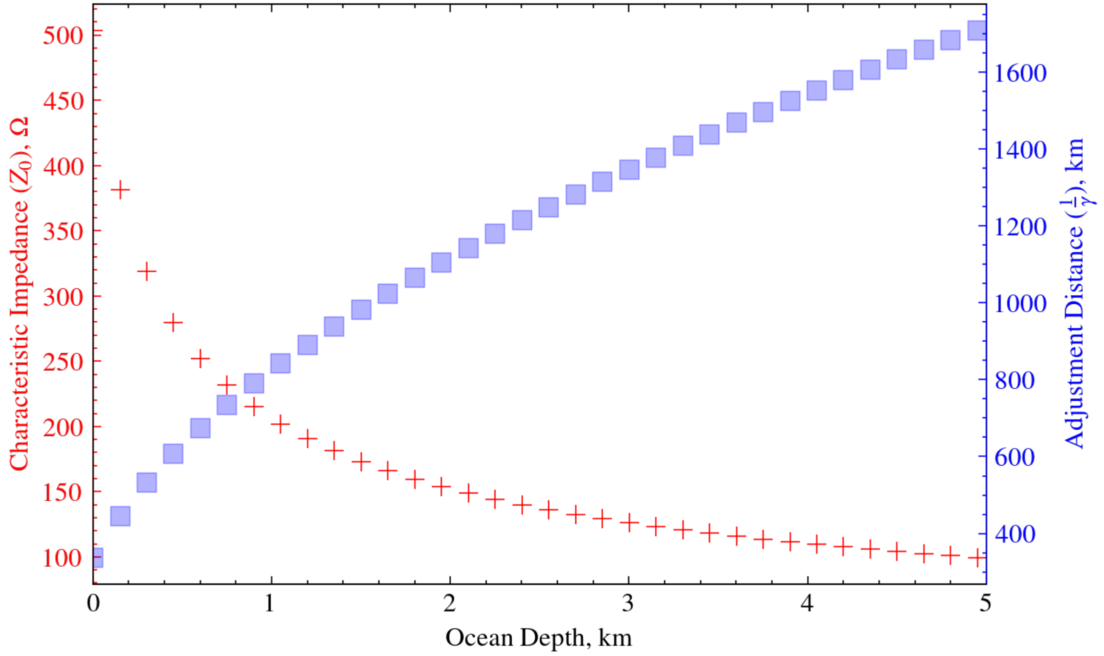
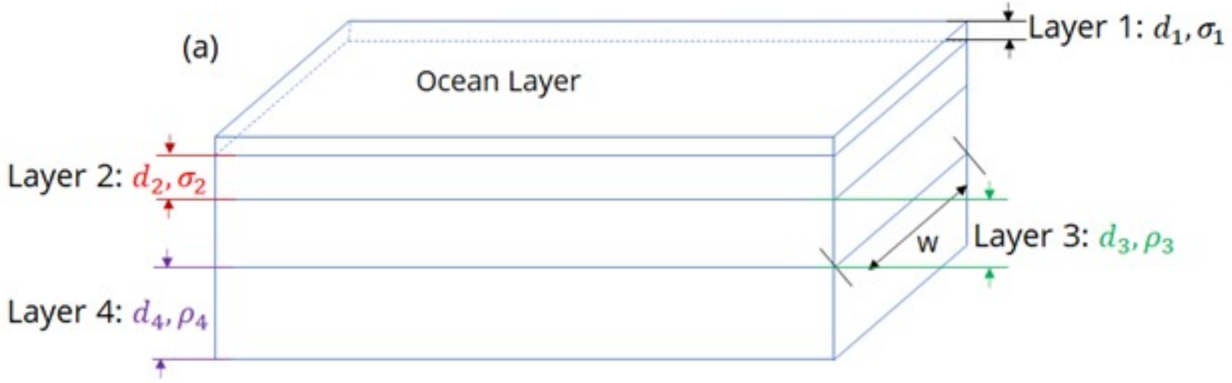
Water Shielding



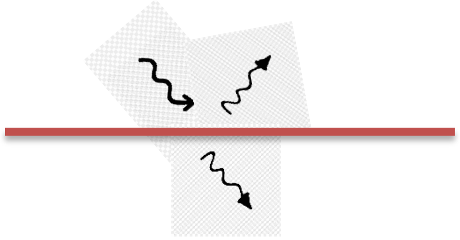




Transfer Function



Layer 1. Ocean Layer
Layer 2. Sedimentary Layer
Layer 3. Crustal Layer
Layer 4. Mantle Layer

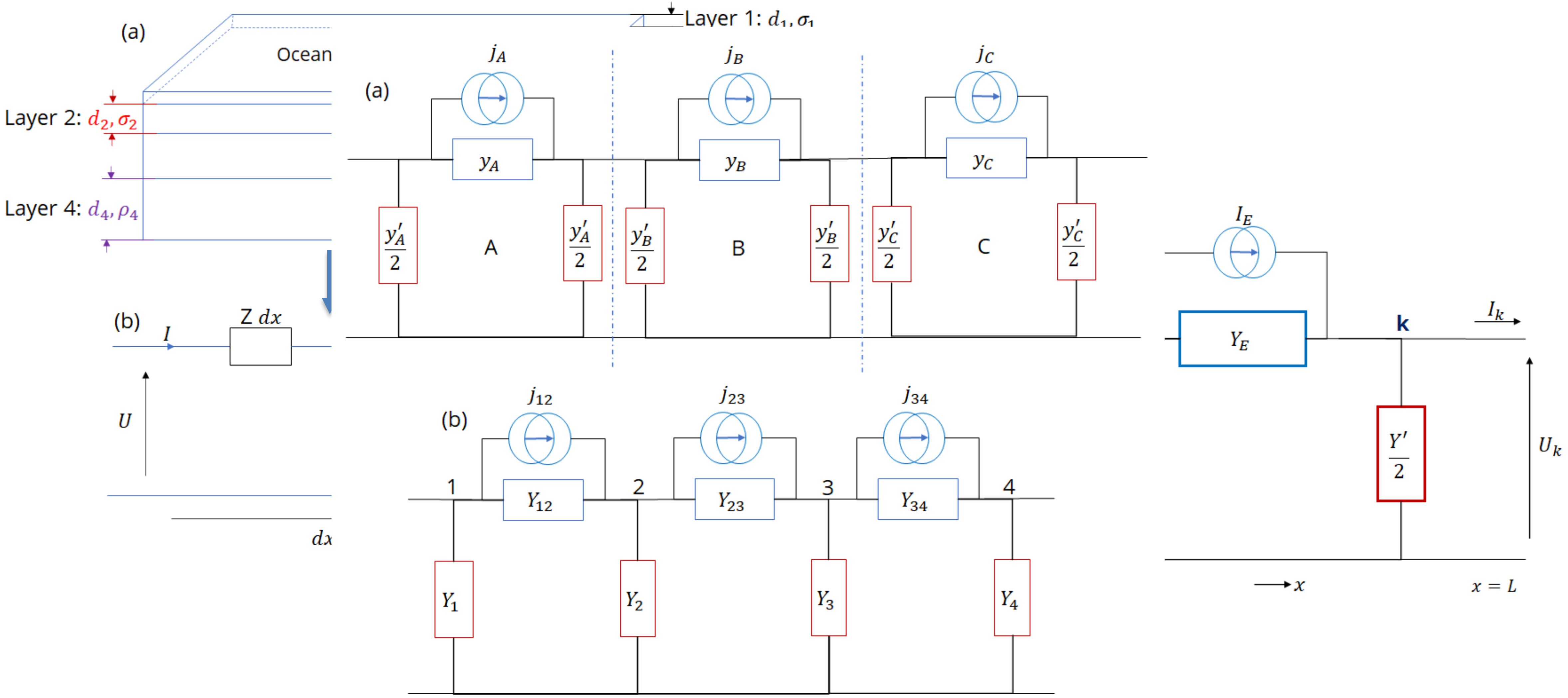


- Estimate reflection coefficients for each layer (Γ), and effective reflection coefficients (Γ_e)
- Estimate impedance (Z) for each layer and effective impedance (Z_f) at the sea-surface.
- Use sea water depth (d) to estimate transfer function (Boteler et al. 2003)

$$\frac{E_f}{B_s} = \frac{Z}{\mu_0} \cdot \frac{2}{\left(1 + \frac{Z}{Z_f}\right) e^{kd} - \left(1 - \frac{Z}{Z_f}\right) e^{-kd}}$$

where: Z and k are characteristic impedance and propagation constant of the sea water layer.

Distributed Source Transmission Line Model



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