Exploring the Combination of VLF Transmitters and Lightning Emissions for D-region Ionosphere Remote Sensing

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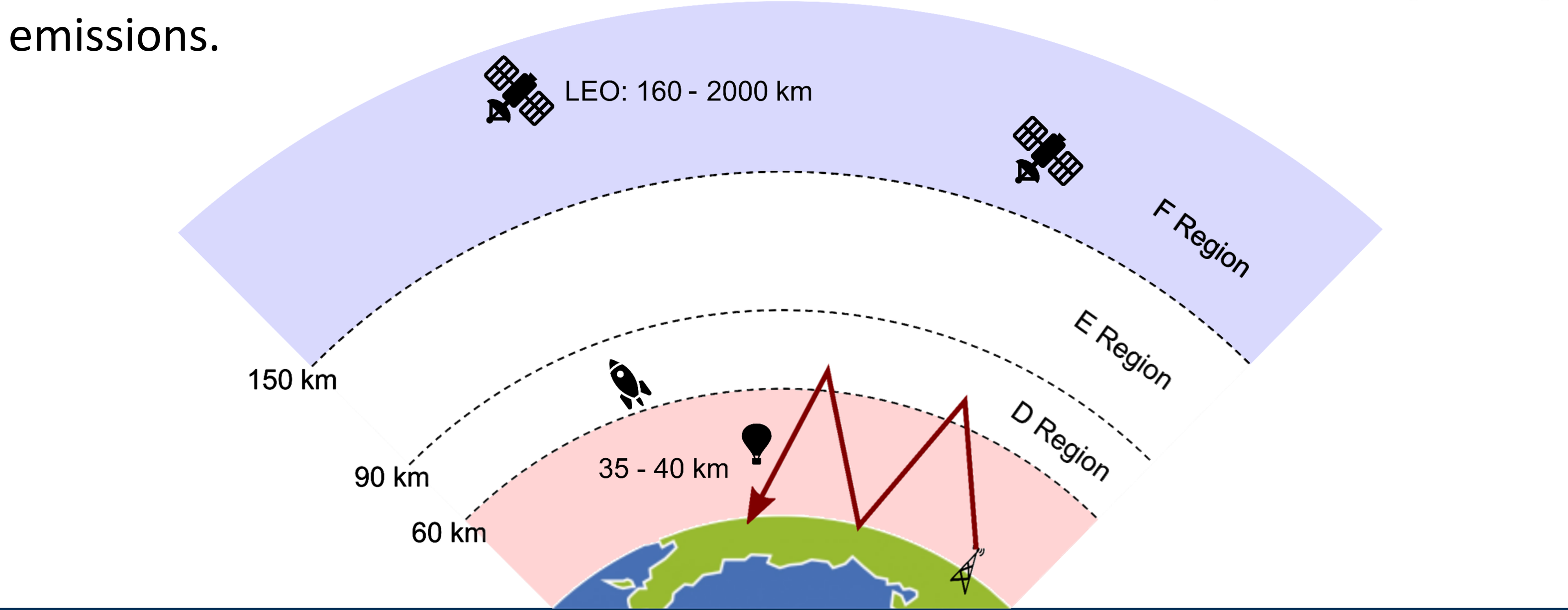
Abstract

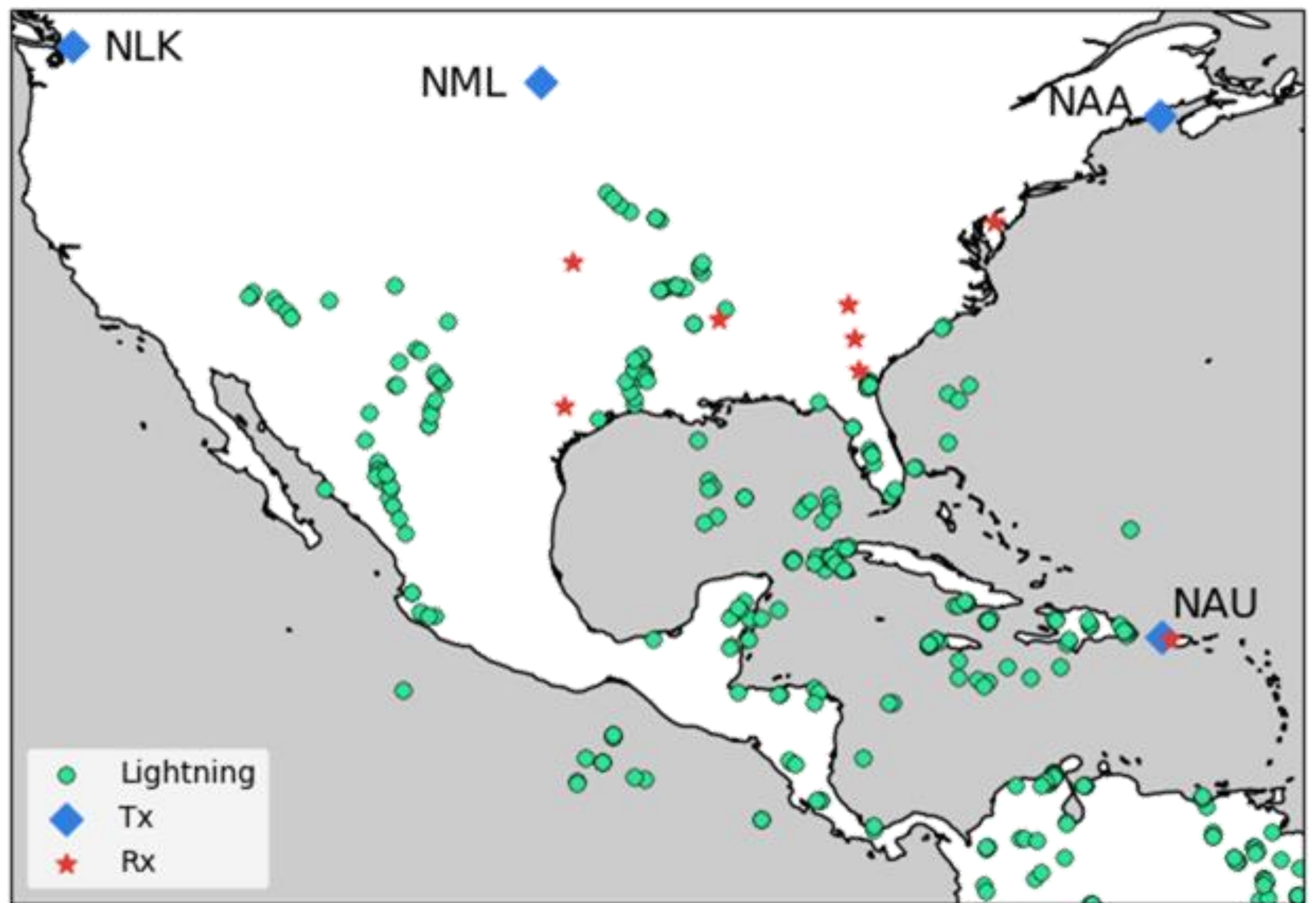
The D-region ionosphere (60-90 km in altitude) is critical for long-range communication; however, it is outside the altitudes reachable by both high-altitude balloons and satellites making direct measurements of its electrical properties difficult. Instead, researchers have often relied on very low and low frequency (VLF, LF) radio waves, typically from either VLF transmitters or lightning, in combination with remote sensing techniques to infer properties such as electron density. While these two sources of VLF and LF radio waves provide different information, they have not been used together to form a single, cohesive model. In this work, we explore a tomography-based approach to better understand how these two VLF sources can be used together and what limitations may exist. We also examine the differences in available information between the narrowband, but consistent VLF transmitters and the broadband, but sporadic lightning emissions.



Experimental Setup

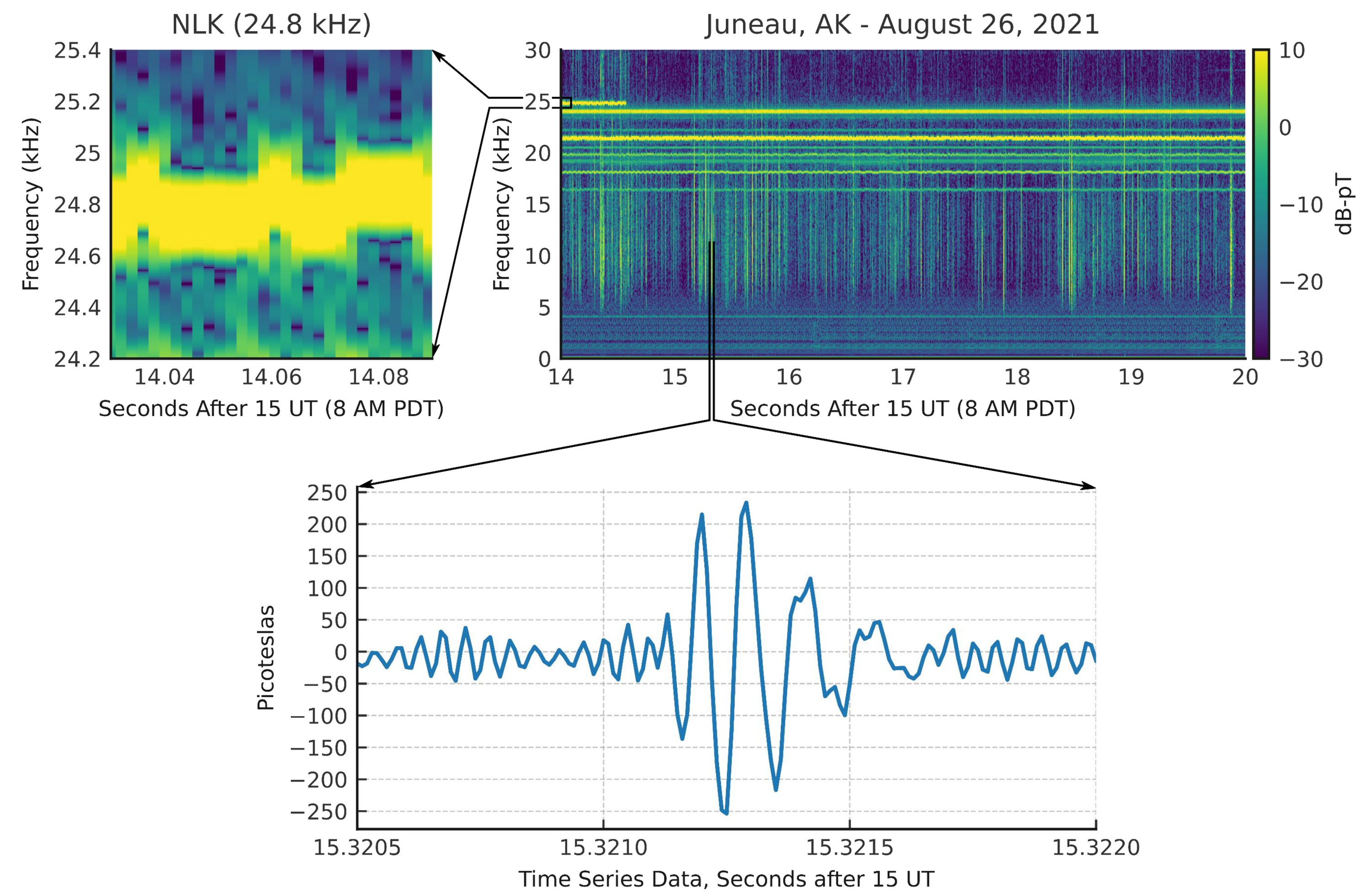
VLF waves can travel long distances via the Earth-ionosphere waveguide. At each reflection from the ionosphere, the wave's amplitude and phase are affected. By analyzing the received signals, it is possible to back out information about the state of the ionosphere along the wave's path.

This works used eight Georgia Tech VLF receivers detecting VLF waves from three Navy transmitters as well as sferic emissions from lightning.



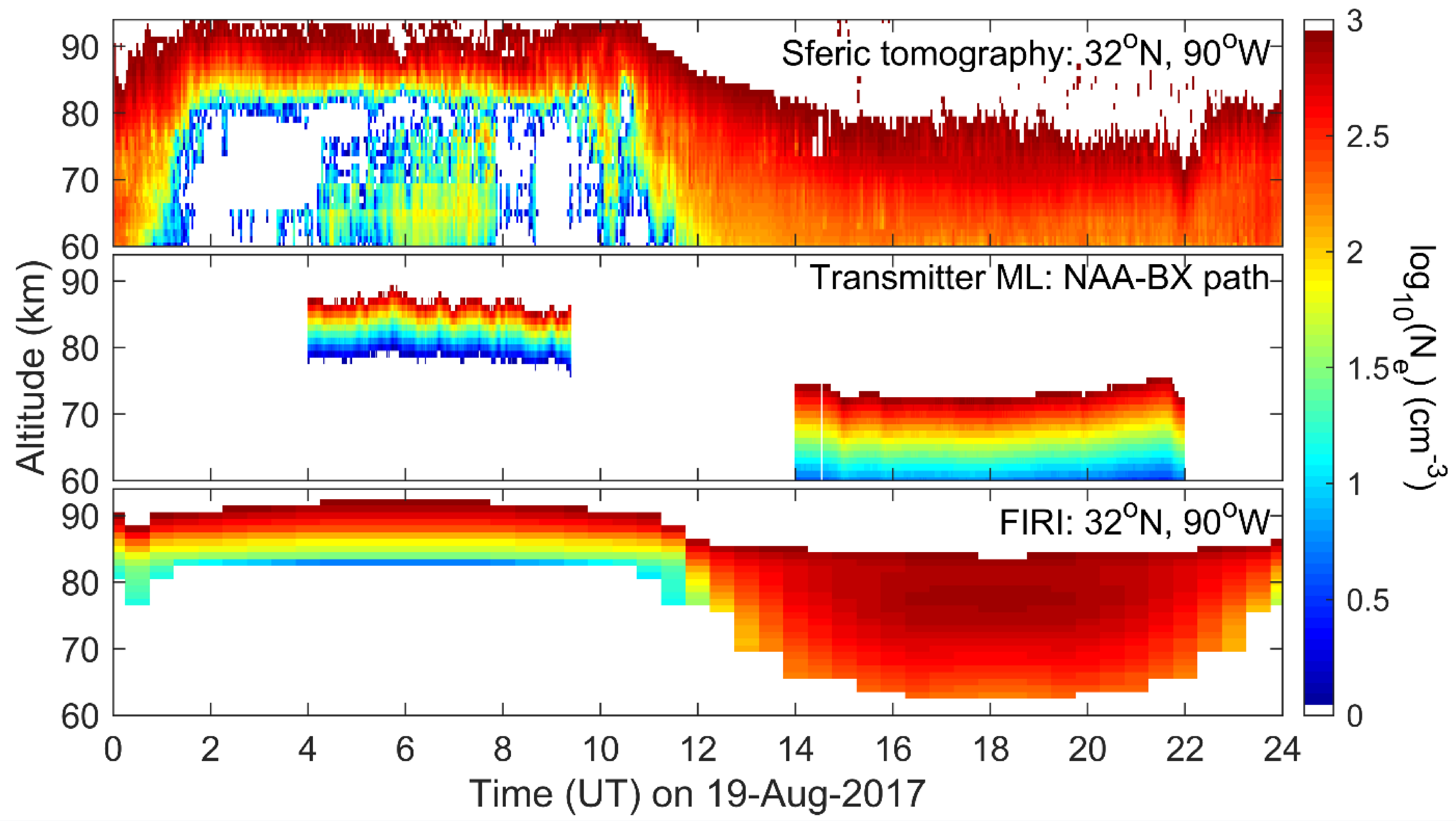
Measured Data

Narrowband (horizontal lines) VLF transmitters provide a temporally consistent, high-power signal to analyze the ionosphere's response to a narrow frequency band with high time resolution. Broadband sferics (vertical lines) provide a temporally and spatially random signal which provides insight into the ionosphere's electrical properties at multiple altitudes with high spatial resolution.



Transmitter vs Sferic Comparison

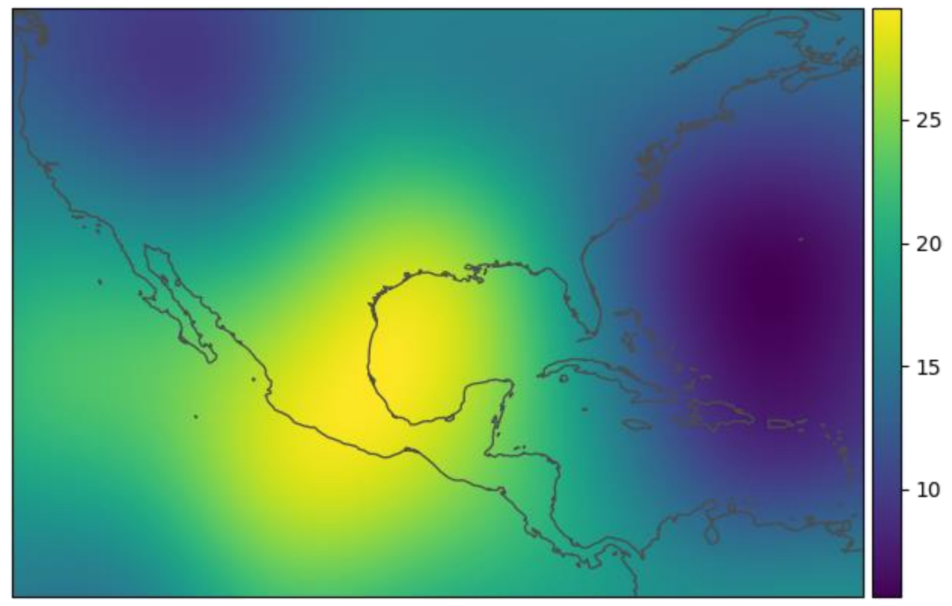
To understand the potential for a unified D-Region model, we must examine the available data sources, as well as how those data sources are being used currently. Prior work has shown the capability to predict path average electron density from VLF transmitters. Additionally, a recent model used emissions from lightning, known as sferics, in a tomography-based model to generate an electron density map over the Gulf of Mexico and part of the South-East US. Below is a comparison of these two techniques, as well as the FIRI model.

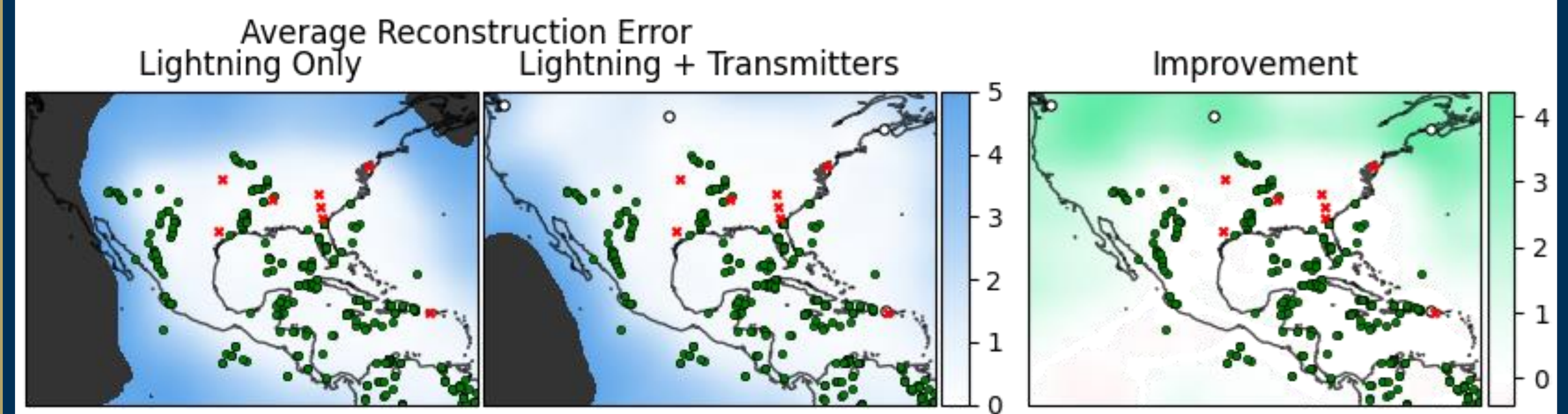


Synthetic Tomography

With the help of random synthetic feature maps, it is possible to understand how introducing VLF transmitters into a tomographic inversion will improve the spatial coverage. These feature maps are generated using a sum of gaussians to account for the expected spatial variations within the ionosphere. An example is shown below.

By generating many these feature maps, introducing some random measurement error, then applying tomography, we can see that introducing VLF transmitters into the model allows a significant northward shift in the low-error region (below).





Summary

- Examine the existing state of the art for both VLF transmitter and Sferic-based D-region ionosphere remote sensing techniques
  - Models agree reasonably well when adjusted for differing locations
- Demonstrate the use case for VLF transmitters in a tomography-based approach to increase the low-error region
  - Performed in the synthetic case for now, but will be extended to real-world data soon

References and Contact

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