# Integrating Spaceborne GNSS-R Measurements in 3D Ionospheric Imaging: A Simulation Study

Brenna Royersmith, Brian Breitsch, Y. Jade Morton
University of Colorado Boulder

SeNSe Lab
Satellite Navigation & Sensing Laboratory
University of Colorado Boulder

SWx TREC

COLORADO CENTER FOR ASTRODYNAMICS RESEARCH

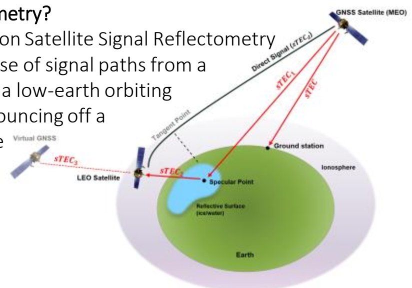
## Introduction

- Main issue with previous studies is the limitations of data source(s) with either good spatial or temporal resolution, difficult to achieve both
- Tomography allows us to utilize the potential of all sources together to fill data gaps
- Establishing the use of GNSS-R to a real application unlocks the door to future potential of using reflected signals
- Research has been done in our lab detecting polar structures using GNSS-R, particularly over polar regions and oceans where receivers are not feasible
- Better data coverage and more ray paths leads to better accuracy and more research opportunity

## Background

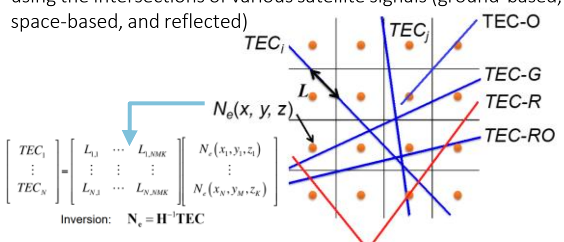
**What is reflectometry?**

- Global Navigation Satellite Signal Reflectometry (GNSS-R) is the use of signal paths from a GNSS satellite to a low-earth orbiting (LEO) satellite, bouncing off a reflective surface (calm ocean/ice)




**What is tomography?**

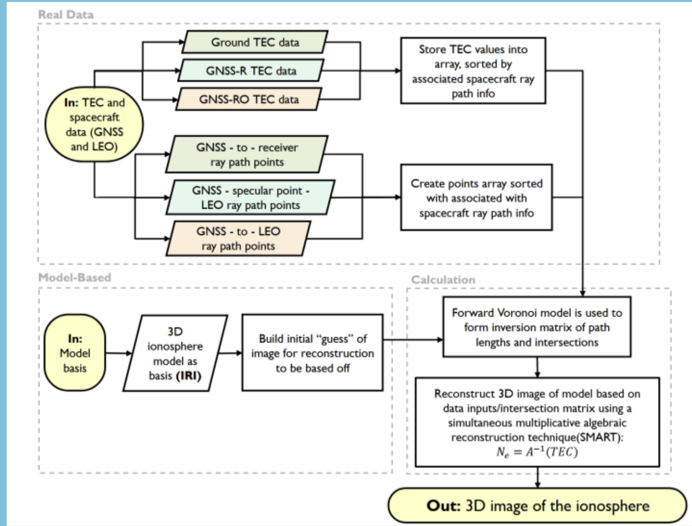
- Three-dimensional model-based ionospheric imaging, updated using the intersections of various satellite signals (ground-based, space-based, and reflected)




**Using a voxel-based method:**

- Break ionosphere into grid of voxels (centers of gripoints)
- Find intersections of ray paths with voxels
- Fill in model using data from ray paths

## Algorithm




## Results

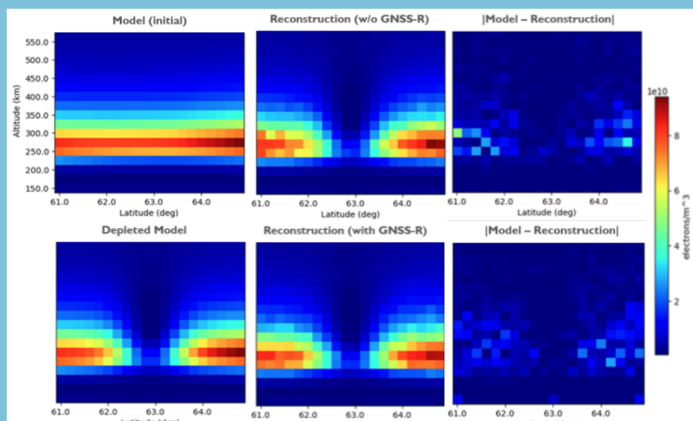



**Figure 1.** Steps of the image reconstruction process. Image slice is taken from 60° to 65° latitude, 100 to 1000 km altitude, at 0° longitude. First column; ionospheric model (top), model with depletion (bottom). Second column; reconstructed image without GNSS-R (top), reconstruction with GNSS-R (bottom). Third column; difference between model and reconstruction, without (top) and with (bottom) GNSS-R. Observe the decrease in difference with GNSS-R

## Diagnostics

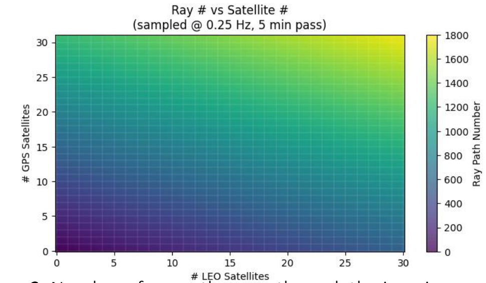



**Figure 2.** Number of ray paths seen through the imaging medium versus number of GPS satellites and number of LEO (Spire) satellites, as indicated by the colorbar.

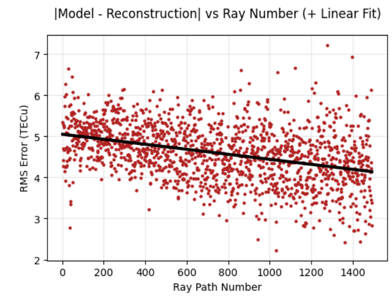



**Figure 3.** RMS of the difference between the reconstructed image and the base model, based on number of ray paths, scattered along with a linear fit line to observe decrease in RMS.

## Visualization

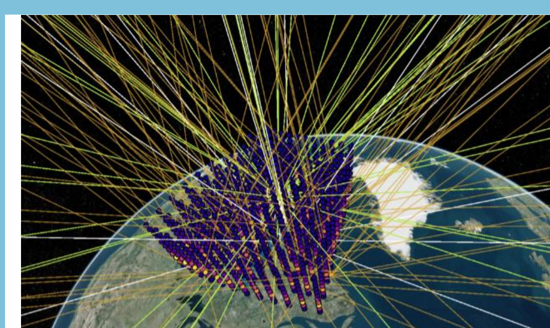


**Figure 4.** Three-dimensional visualization of the tomographic process made using Cesium geospatial software, provided by Brian Breitsch.