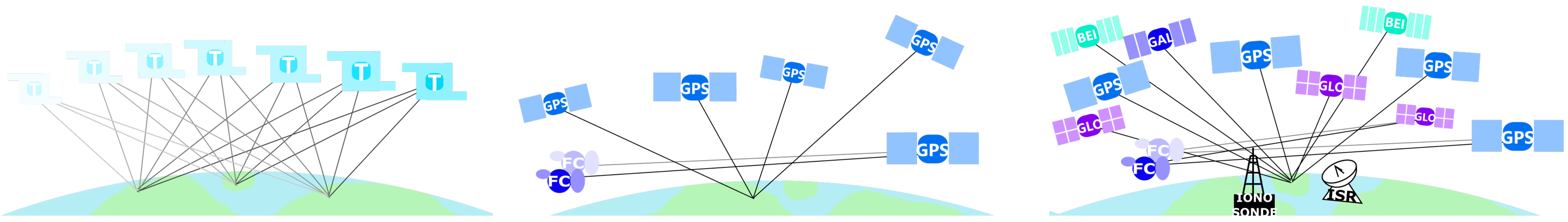
Simulation Experiment for Adaptive Mesh Ionosphere Imaging Using Ground and LEO GNSS Measurements

Student: Brian Breitsch Advisor: Jade Morton

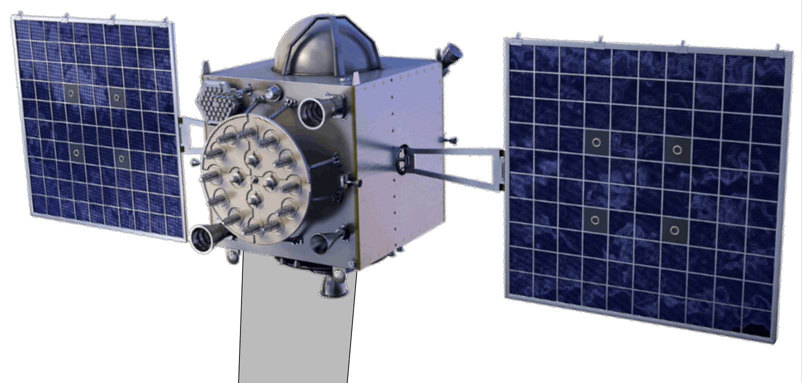
Colorado State University

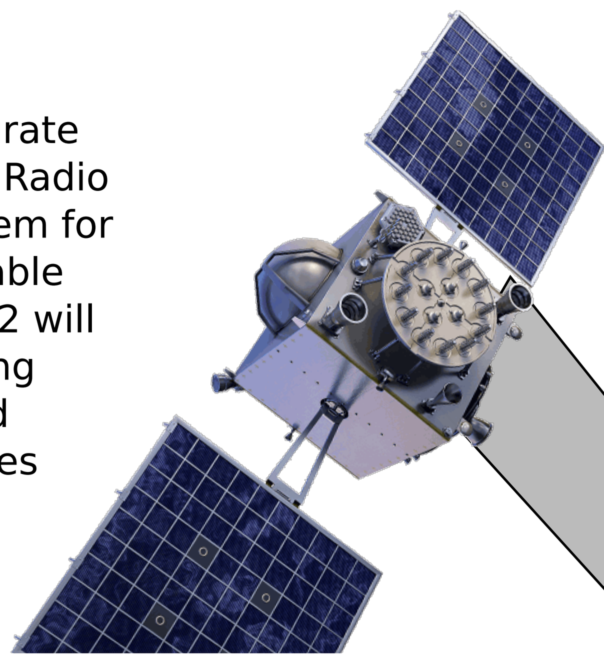
Summary

Here we present preliminary work on a method of ionosphere electron density imaging that aims to mediate information from GNSS signals received on the ground and on low Earth-orbiting (LEO) satetllites. Our focus is on achieving optimal vertical resolution by adjusting the location of nodes in the imaging mesh, which describe a voxel basis for an ionosphere image.



Progression of ionosphere imaging from beacon satellites to multi-constellation GNSS from ground and space receivers





Motivation

The motivation for this study stems from a need to obtain more accurate profiles of electron density in the lower ionosphere, e.g. the E-layer. Radio occultation (RO) observations from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) have provided valuable data for profiling electron density, and its follow-on mission COSMIC-2 will provide even more high-quality data. Traditional tomographic imaging methods have been successfully applied to the ionosphere using grid voxel bases. However, problem sparsity seems to prevent such bases from resolving information at the resolution RO data should provide. Imaging meshes that adapt to the data geometry are promising.

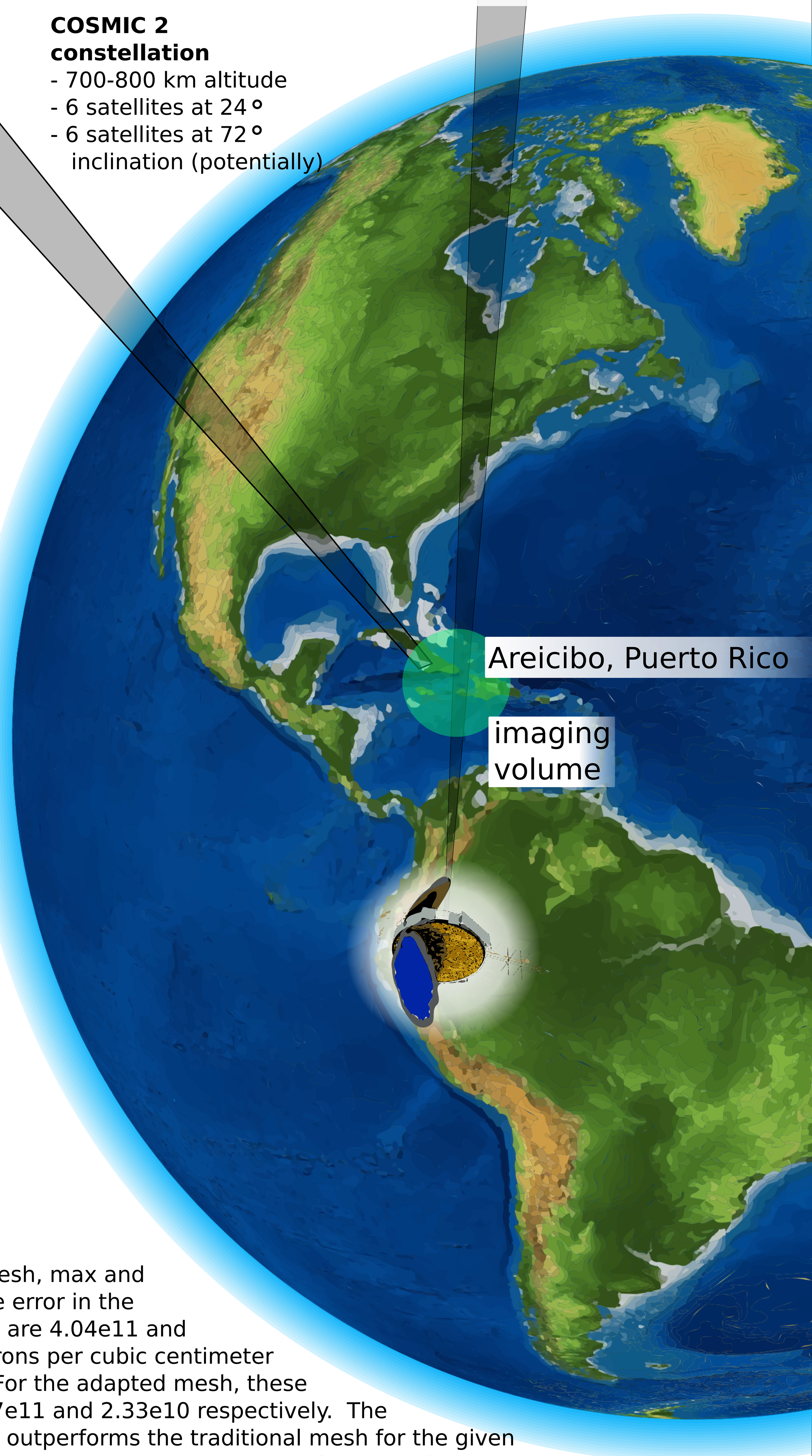
Orbits

GNSS satellite orbits are generated from SP3 orbits. Hypothetical COSMIC-2 orbits are created using appropriate orbital parameters and SGP4 propagation.

GNSS constellations
- 17000-20000 km altitude
- 45° to 65° inclination
- More than 65 active satellites

Valid ray paths:
- elevation angle >5° for ground receiver
- tangent point > 2 km altitude for COSMIC receiver
- 10 minute interval for GNSS ray paths
- 5 second interval for COSMIC ray paths

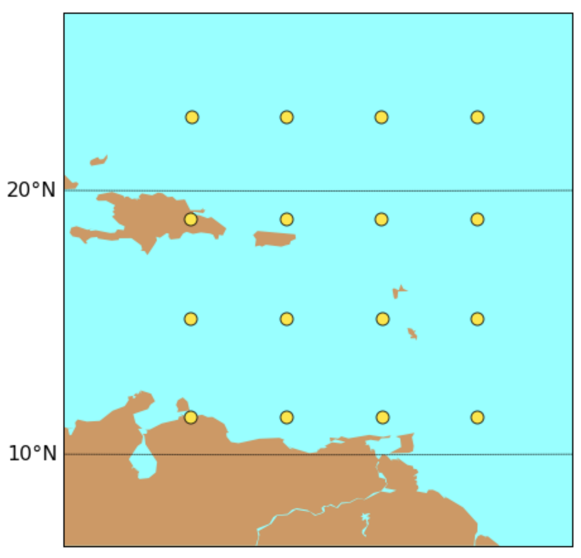
COSMIC 2 constellation
- 700-800 km altitude
- 6 satellites at 24°
- 6 satellites at 72° inclination (potentially)



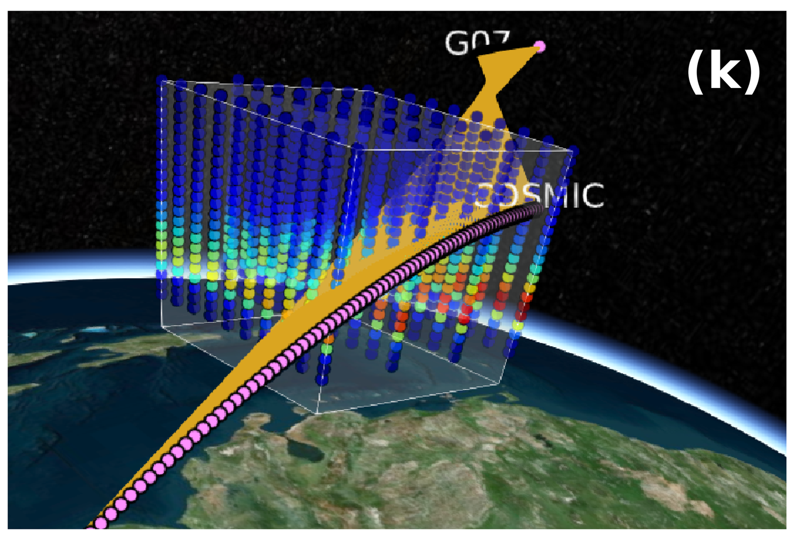
Method

Here we present simulation results for an adaptive mesh imaging technique. The imaging is centered at coordinates 16.5°, -65° lat/lon, which is near Areicibo, Puerto Rico. We choose a time (10:30 local) such that ionization is present and an occultation occurs for our simulated and hypothetical satellite orbit. We then:
- sample the International Reference Ionosphere (IRI) to create a mock electron density image
- perturb this image by adding a multiplicative Gaussian depletion
- generate traditional grid and adapted imaging meshes
- produce ray paths from realistic GNSS and hypothetical COSMIC-2 orbits
- compute the forward projection models
- reconstruct images using the algebraic reconstruction technique and the unpertubed ionosphere as a seed

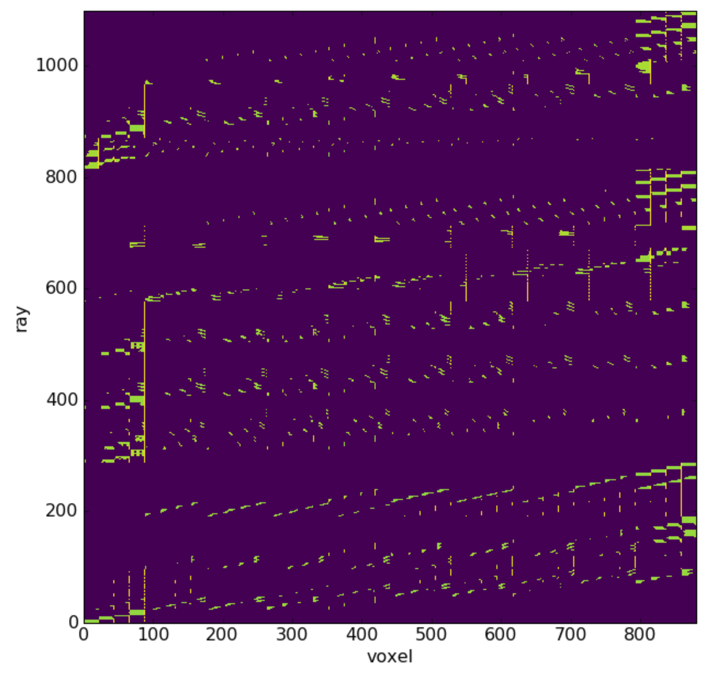
ground receiver spacing



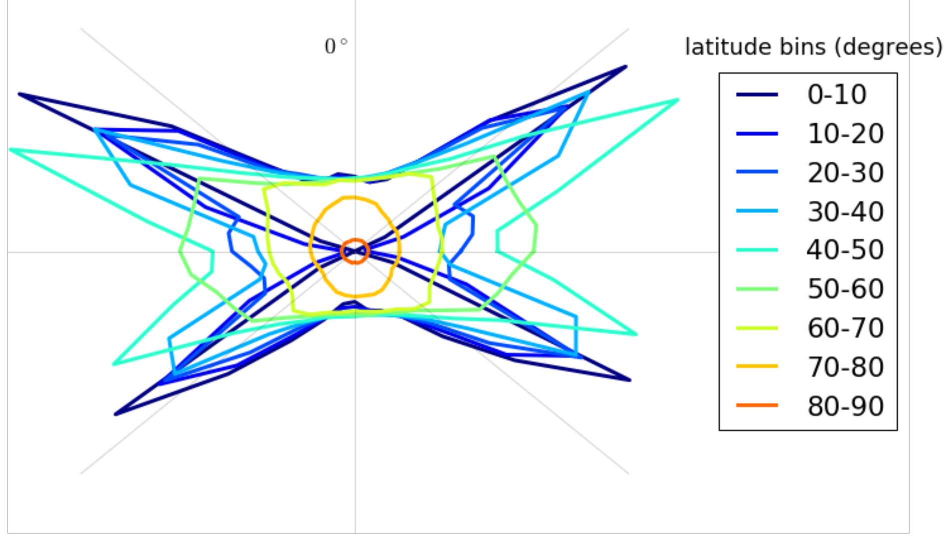
RO geometry and mesh



projection matrix
(shows problem sparsity)



COSMIC-2 ray azimuth relative frequency
(mostly aligned with orbital inclination at low-lat)



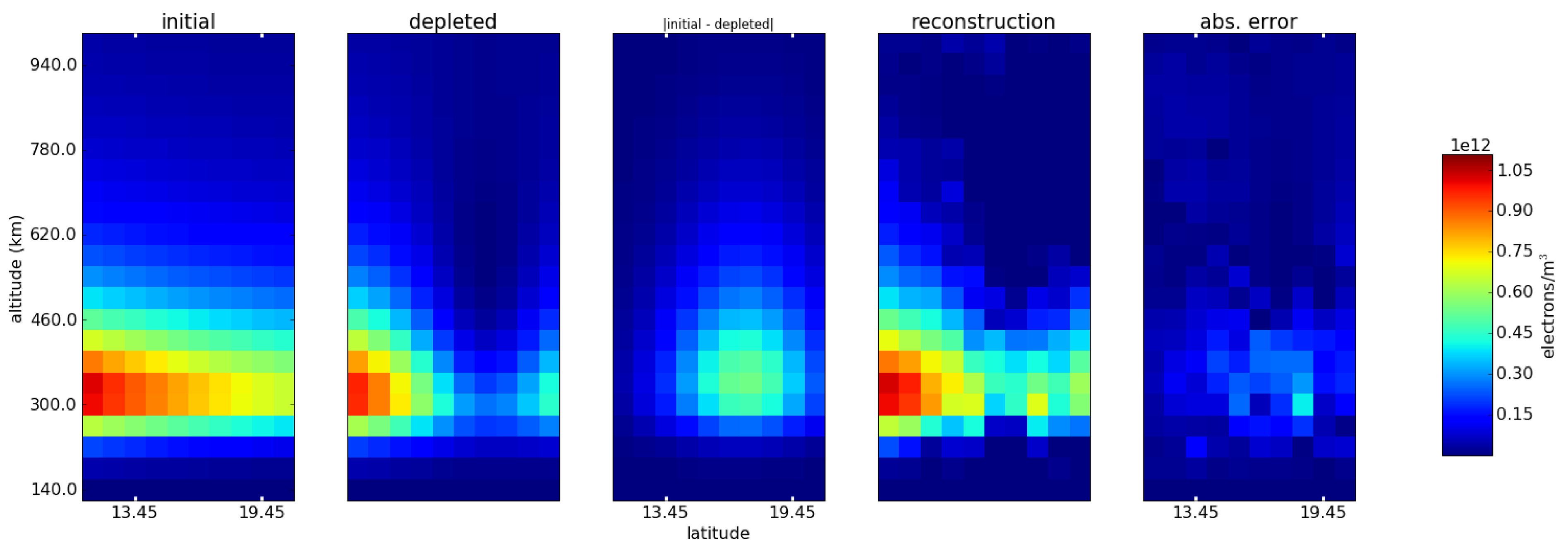
Mesh Generation

Initially, a traditional lat/lon grid is used:

latitude: 11.45° to 21.45° at 1° resolution
longitude: -69.7° to 60.7° at 3° resolution
altitude: 140 km to 980 km at 40 km resolution

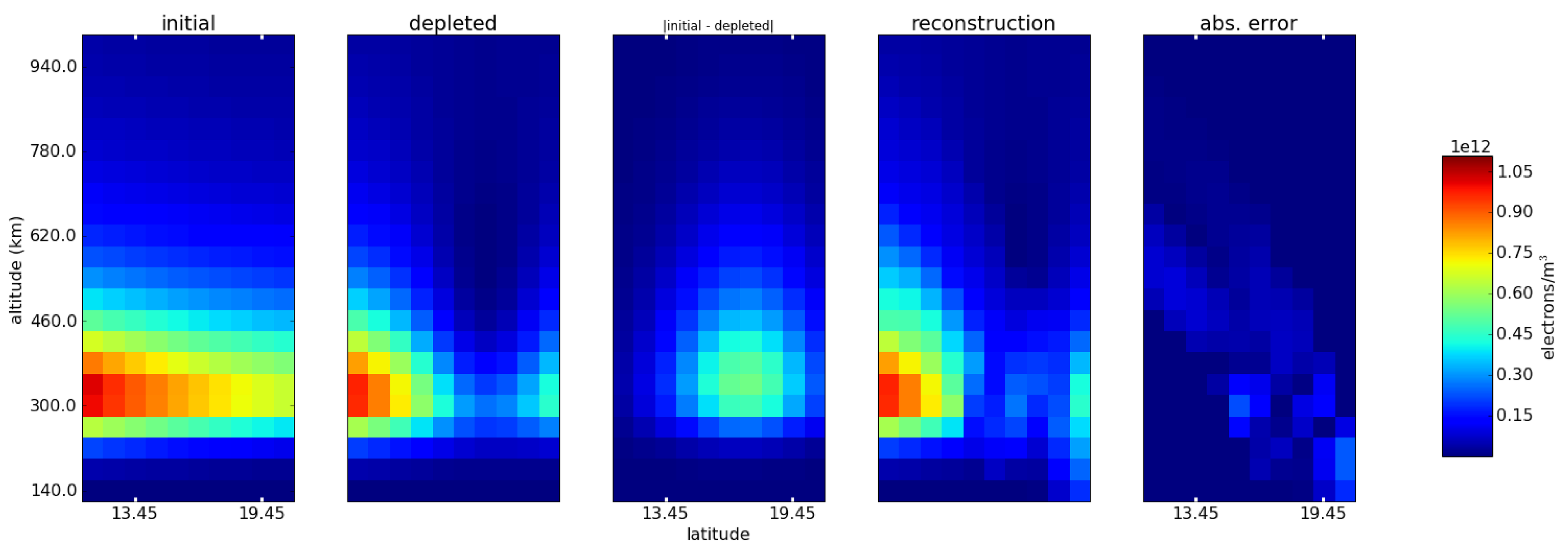
For the adapted mesh, imaging nodes are added along COSMIC ray paths within imaging volume at spacing of 150 km.
Imaging nodes on the original grid and the COSMIC ray paths are combined into one if sufficiently close (<200 km).

traditional mesh imaging results



seed image

adapted mesh imaging results



Results

For the grid mesh, max and mean absolute error in the reconstruction are 4.04e11 and 3.64e10 electrons per cubic centimeter respectively. For the adapted mesh, these errors are 2.37e11 and 2.33e10 respectively. The adapted mesh outperforms the traditional mesh for the given geometry. Reconstruction on the traditional grid has larger errors overall and artifacts at high altitudes. While the adapted mesh reconstruction shows lower errors, there are artifacts present at lower altitudes that are not present in traditional grid reconstruction. This result seems to indicate that adaptive mesh for ionosphere imaging could prove effective, but that more factors need to be taken into account, esspecially considering that our aim is to more accurately image the lower ionosphere.

Future Work

While many assumptions are made in the course of this simulation, we hope to implement and test the irregular/adaptive mesh method using real-world data. Dealing with TEC contributions outside the imaging region will require models for topside and possibly contribution from data assimilation models such as GAIM. A quantitative analysis of adaptive mesh imaging simulation results is necessary, as well as simulations under a wider variety of conditions, including multiple simultaneous RO observations.