Tomography of the Low-Latitude Ionosphere: Simulations and preliminary results

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Abstract

This work presents preliminary results of tomographic reconstructions of simulated ionospheric electron density using different algebraic reconstruction and regularization techniques. Ionospheric profiles from the IRI-2016 model and Ionosonde data were used. First results of the design of a low-cost total electron content (TEC) receiver are also shown.

I. Introduction

Spread F irregularities change the propagation environment of radio signals. Although they have been studied thoroughly, their dynamics in 3D is still an active topic of research. The project goal is try to estimate the spatial distribution of these irregularities to improve our understanding on the physical mechanisms [1].

Algebraic reconstruction techniques have the advantage that are easy to implement and do not require high computational processing. We use and analyze the difference and the advantages of two iterative algebraic methods ART and MART [2]. On the other hand, Tikhonov regularization approaches have the advantage of allowing the construction of functionals informed by the physics of the phenomena. Tikhonov methods proposed by Lee [4] and Comberiate [3] were implemented.

TEC information to obtain ionosphere profiles will be provided by ground receivers which process signals from LEO satellites. The goal from the hardware perspective is to build a low-cost TEC receiver to increase spatial coverage of the tomographic reconstructions.

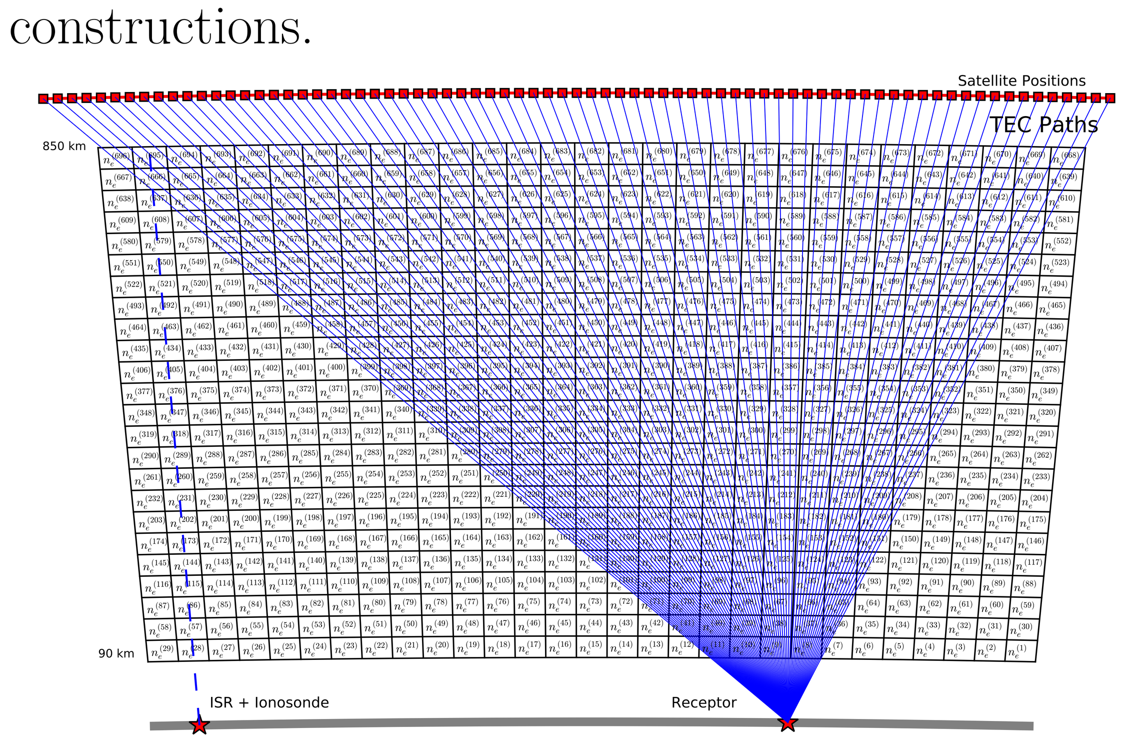

Figure 1 – Illustration of the discretized ionosphere and the TEC paths between the satellites and the receptors.

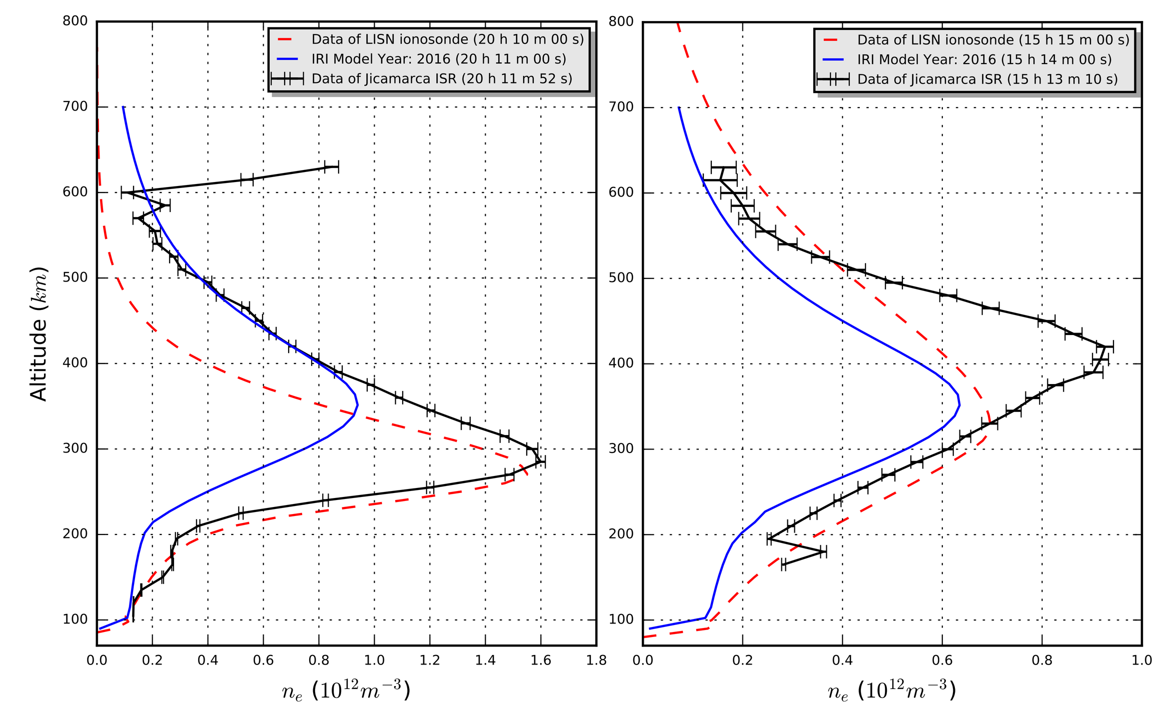

Figure 2 – Comparisons of n_e data between Ionosonde data, ISR and IRI for the indicates times.

II. Inversion Methods

Two-dimensional cuts of the ionosphere, containing the satellite receiver trajectories, are discretized into a grid such that the electron density in each cell can be approximated to be constant (see Figure 1).

For the simulation of the ionosphere (Figure 3), we use Chapman profiles and IRI density estimations. Irregularities were included using Gaussian functions [2].

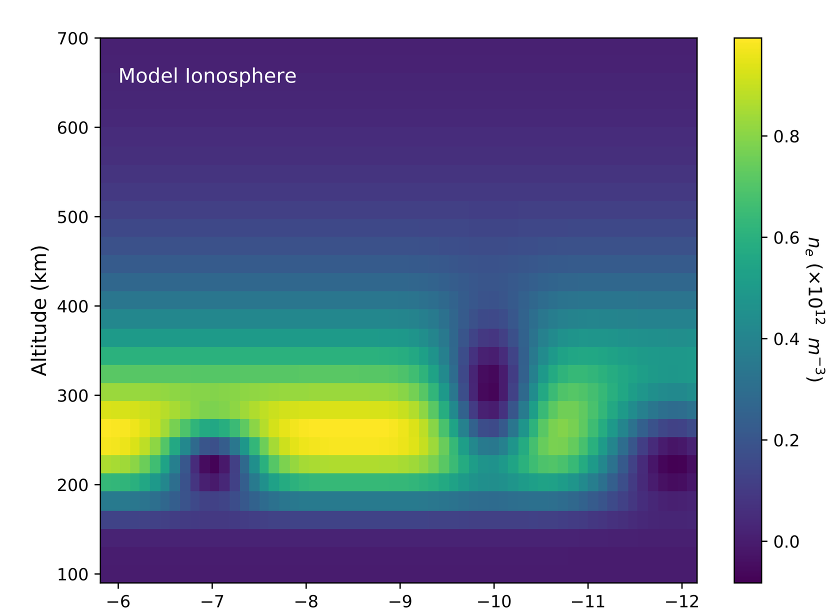

Figure 3 – Simulation of Ionosphere Model

We used two different algebraic reconstruction algorithms:

$$n_e^{(k+1)} = n_e^{(k)} + \lambda \frac{b_i - \langle A^i, n_e^{(k)} \rangle}{\langle A^i, A^i \rangle} A^i \quad (1)$$

$$n_e^{(k+1)} = n_e^{(k)} \left(\frac{b_i}{\langle A^i, n_e^{(k)} \rangle} \right)^{\lambda \frac{A^i}{\langle A^i, A^i \rangle}} \quad (2)$$

Where Eqn.(1) and (2) correspond to the ART and MART methods, respectively [2]. The regularization methods implemented penalized variations in the solution for different directions. Figure 4 shows a comparison between the estimates from these methods.

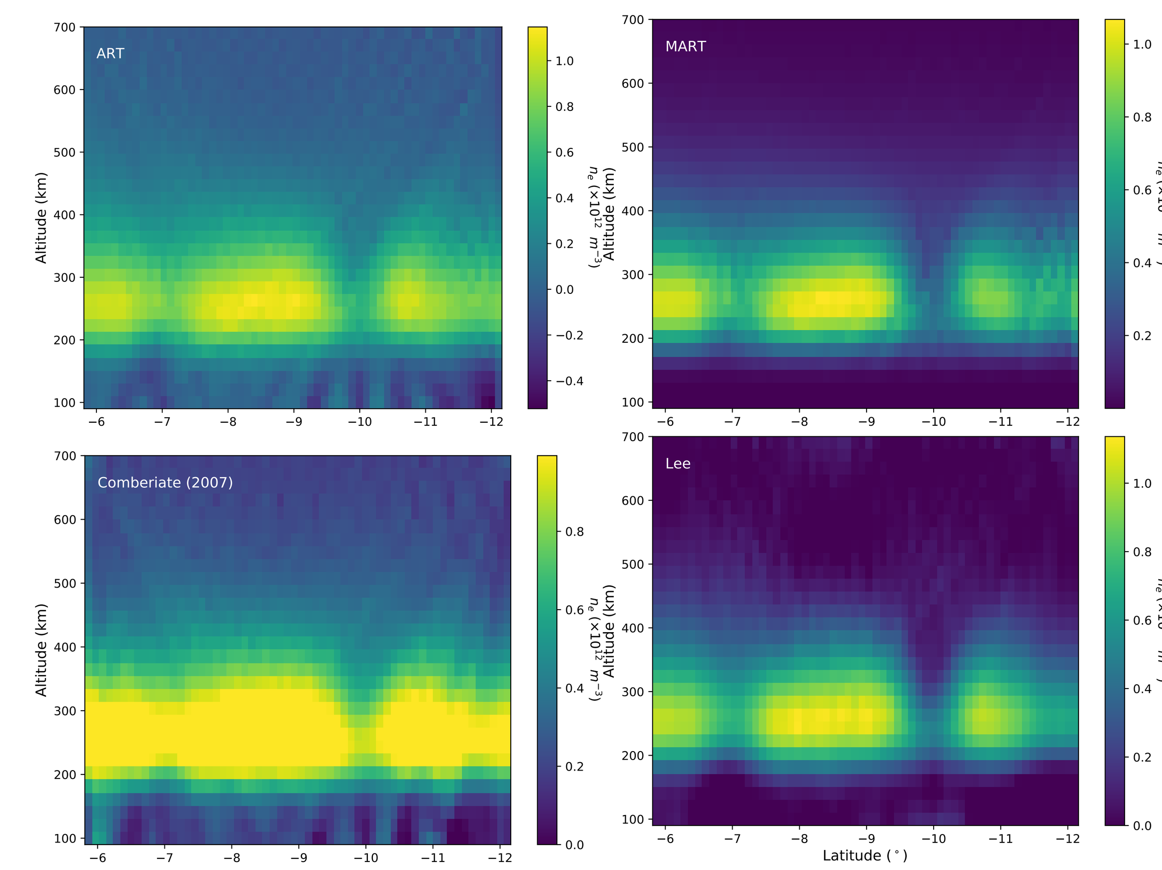

Figure 4 – Algebraic reconstructions (ART and MART) are shown in the first row. Estimates from the methods proposed by Lee [4] and Comberiate [3] are shown in the second row.

III. Hardware and Experimental considerations

The phase difference from a TEC receiver was simulated to assess the performance of the USRP and the BladeRF architectures (Figure 5). The phase results are shown for 60 dB as well as the mean phase error for different SNR. BladeRF's mean error phase is around 0.4 rad greater than the USRP's. Further improvements on the simulation and tests with these systems will enable us to determine the hardware specifications for the receivers.

Figure 6 shows an example of reconstruction plane built using CASSIOPE's ephemeris and taking into consideration LISN's Ionosondes locations.

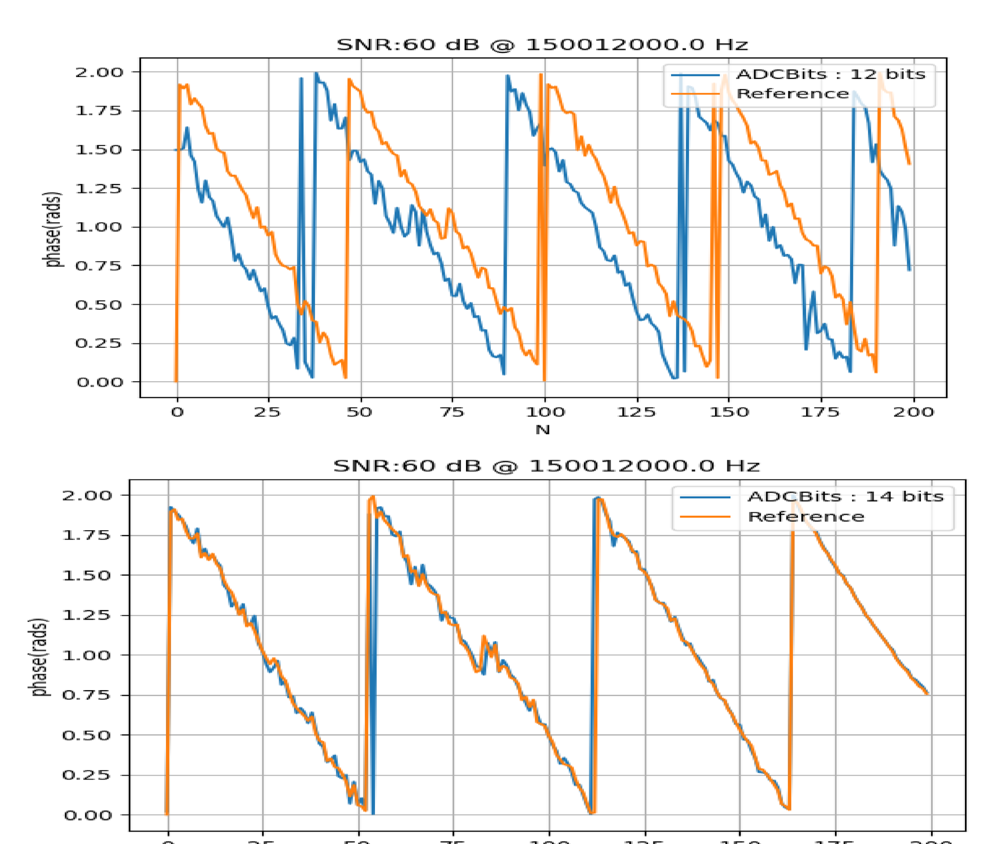

Figure 5 – BladeRF (a) and USRP (b) phase estimations (blue) and a reference signal (orange).

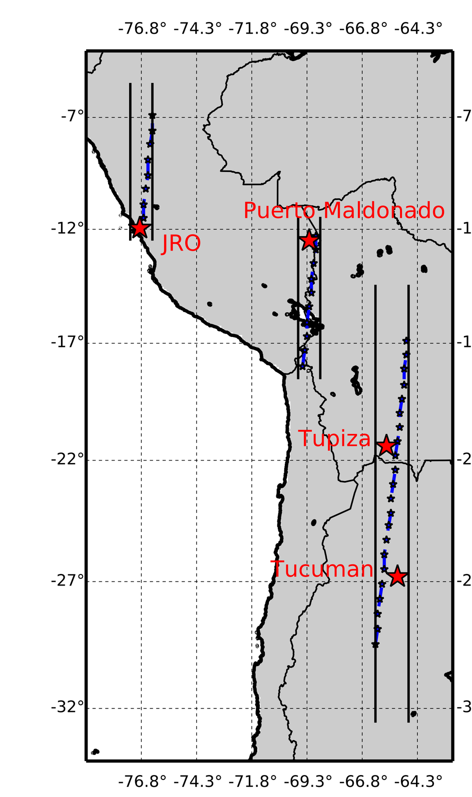

Figure 6 – Example of possible reconstruction planes on the LISN network.

IV. Future Work

We are working on improving the priors for the tomographic reconstructions by analyzing the discrepancy between digisonde and ISR estimates, and improving ionosonde density estimates with regularization methods. Also, Montecarlo simulations are being developed to compare the different regularization methods on various experimental scenarios. Finally, we will use the results from the receiver simulations and SDR tests to design and build a TEC receiver.

Conclusions

- Ionosonde data complemented with IRI estimates can be used as priors and penalizing criteria for tomographic inversions.
- MART and the method proposed by Lee [4] seem the most promising options so far.
- BladeRF showed good results but experimental data need to be recollected.

References

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