Full-Profile Analysis of the Polar Topside Ionosphere

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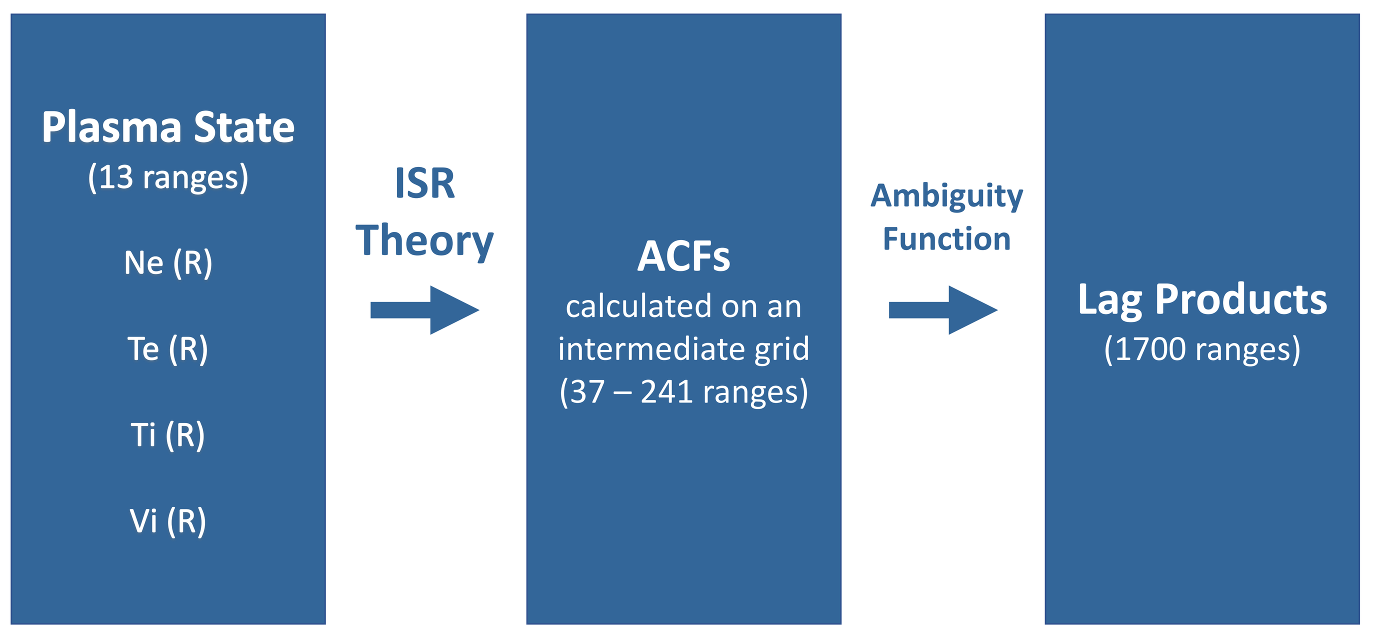
Abstract:

We undertake a full-profile analysis of incoherent scatter radar data from the RISR-N and RISR-C facilities in order to characterize the polar topside ionosphere up to ~1800 km. This approach uses both very long pulses (1.5 ms) to reach the topside, and the expected smoothness of the plasma profiles to regularize its solutions. Preliminary results show expected values for electron density, and for electron and ion temperature, for ranges up to 800 km. Above that we are limited by the quality of the data.

Motivation:

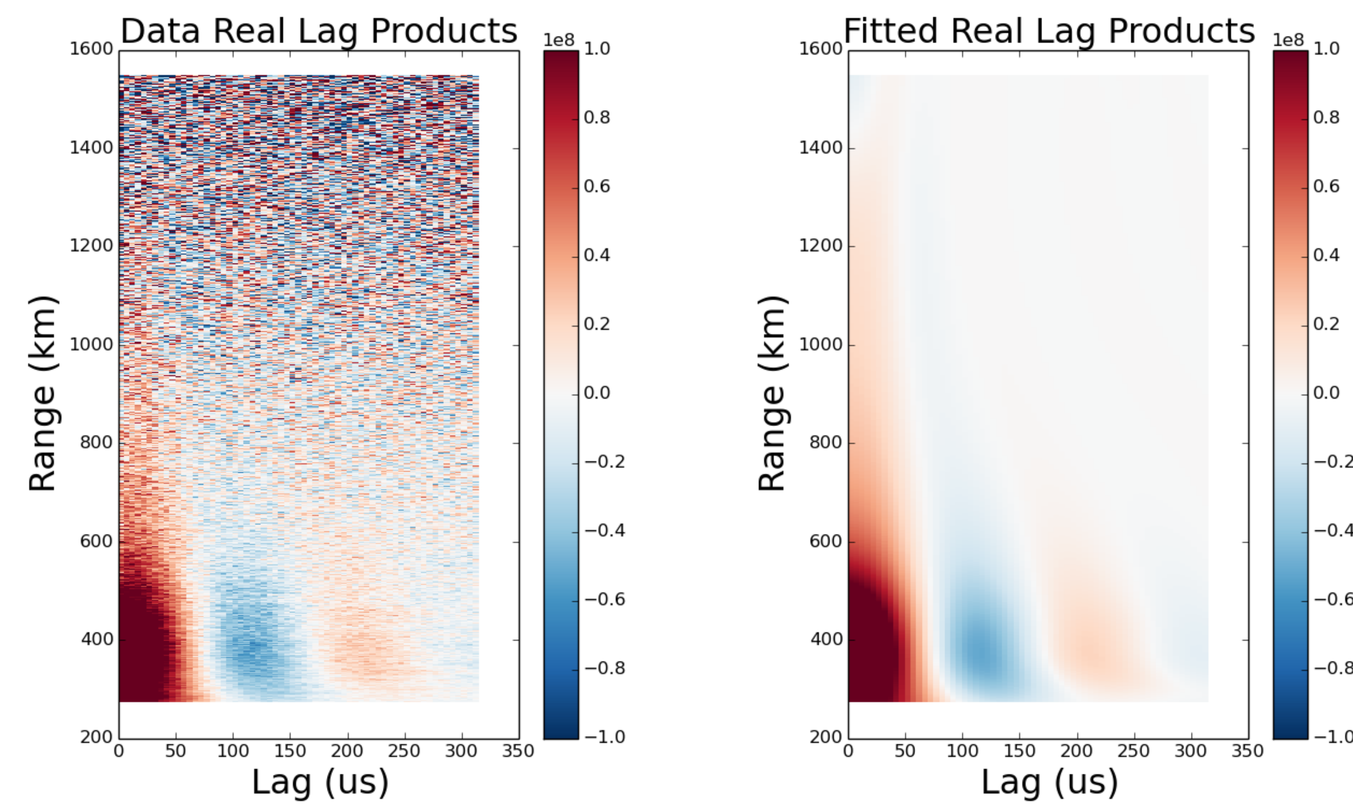
The polar cap ionosphere is of particular interest as the region where ion outflow begins, but its structure is still poorly understood. The RISR-N and RISR-C facilities at Resolute Bay, Canada, provide an opportunity to study this region at unprecedented magnetic latitude (~83º) and altitude (>500 km). Previous conventional incoherent scatter radar studies have used shorter pulse lengths (480 μs), which are not suitable for probing the topside ionosphere, and gated analyses, which do not permit regularization of their solutions. The present study uses very long pulses (1.5 ms) and full-profile analysis to better characterize the structure of the polar topside ionosphere.

Forward Model:

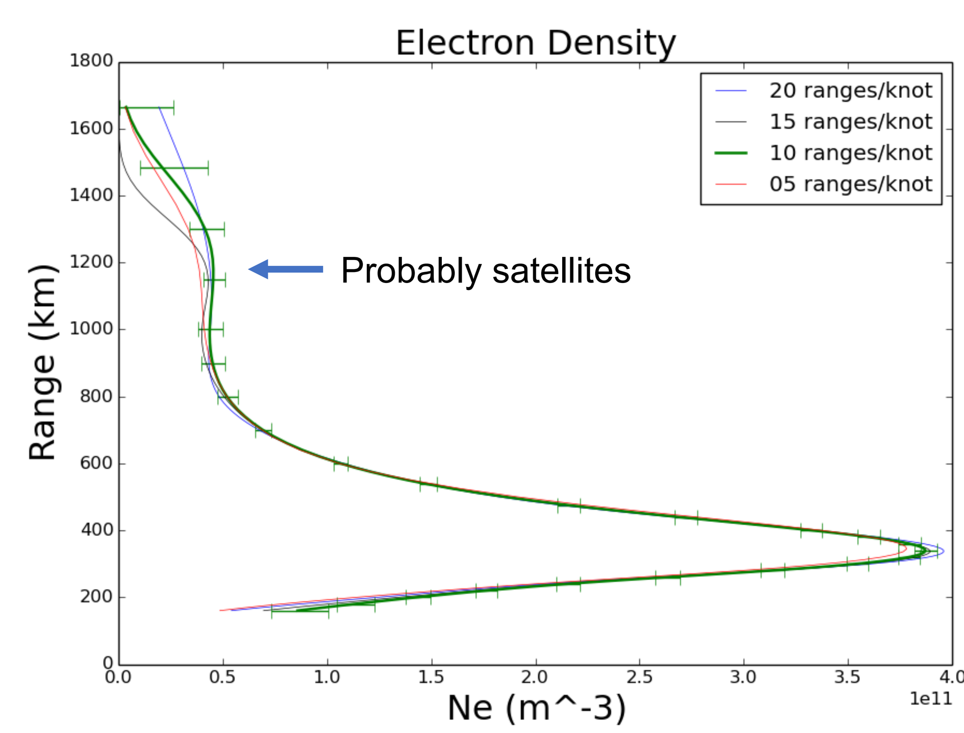


The plasma state is represented at thirteen non-uniformly spaced ranges, which serve as knots for cubic spline interpolation. The ACFs are calculated on an intermediate grid, which adds a number of uniformly spaced ranges (5, 10, 15, 20, etc.) between each knot. The ACFs are then convolved with an ambiguity function to generate the lag products at 1700 ranges.

Results:

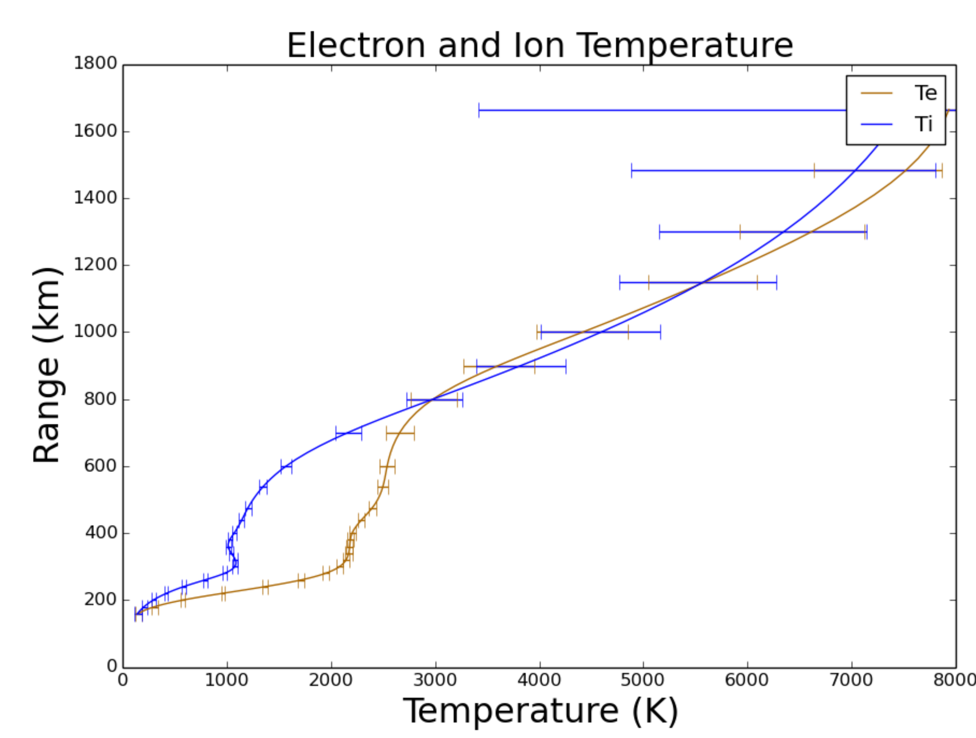


Data real lag products (left) and fitted real lag products (right) for RISR-N data from 4-28-2016, 00:45. The integration time for the data is 5 minutes. The fit uses an intermediate grid of 10 ranges per knot (130 total ranges) to calculate the ACFs.



Electron density for RISR-N data from 4-28-2016, 00:45 using four different intermediate grid resolutions. The fit is sensitive to the intermediate grid resolution, especially above 800 km where the data quality is poor. Error bars are given for the fit using the intermediate grid with 10 ranges per knot (130 total ranges). The small bump around 1200 km is probably caused by satellites that are difficult to clean from the data.

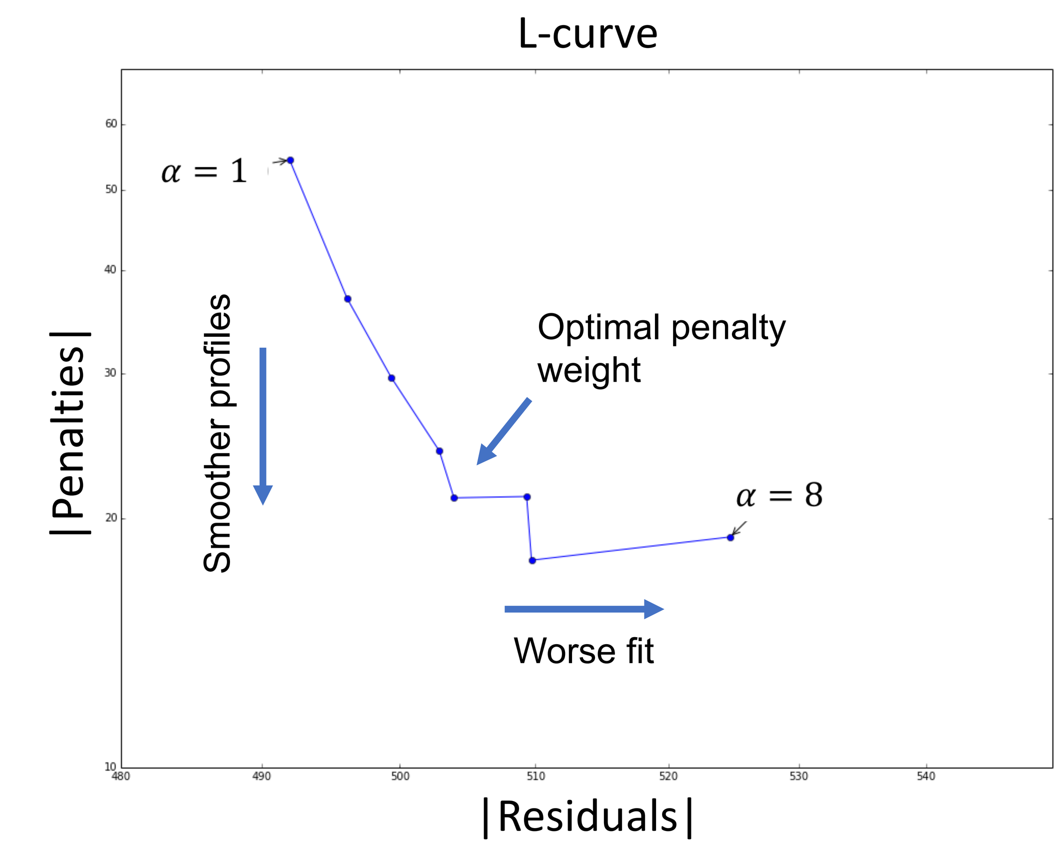
Electron and ion temperature for RISR-N data from 4-28-2016, 00:45. The ACFs are calculated on an intermediate grid with 10 ranges per knot (130 total ranges). As expected, electron and ion temperatures converge around 800 km and then continue to increase with range.



Regularization:

$$\chi^2 = \left(\frac{\text{data} - \text{model}}{\text{errors}}\right)^2 + \alpha(\text{penalties})^2$$

Since there are many plasma states that would fit the data equally well, we add penalty functions to χ^2 in order to discriminate among the possible solutions. We encourage the profiles to be smooth by penalizing their second derivatives. The penalties are tuned by adjusting their weight, α, to find an optimal compromise between smoothness and fit. This optimal weight lies at the corner of an L-curve.



This L-curve plots the magnitude of the fitting penalties against the magnitude of the residuals for RISR-N data from 1-21-16, 19:00. To encourage smooth profiles, we penalize their second derivatives. The optimal penalty weight lies at the corner of the L, where small gains in smoothness come at the cost of increasingly poor fits.

Conclusions:

- The plasma profiles look as expected up to 800 km.
- L-curve analysis provides a reasonable way to set regularization parameters.
- The estimation of electron density is affected by satellites that are difficult to clean from the data.
- Above 800 km we are limited by the quality of the data.

Acknowledgements:

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