Resolving Cross Range Gradients in the High Latitude Ionosphere

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Introduction

One of the most important aspects of the physics in the high latitude ionosphere are the spatial gradients of the plasma parameters. In order to understand the physics reasonable measurements of the gradients are necessary.

Incoherent scatter radar systems can resolve gradients in the range dimension. But if scanned through an area of interest, either physically or with the use of electronically scanned phased arrays, they can resolved cross range gradients. To show the ability ISR systems to resolve these gradients a full ISR simulation is used. We show examples with large gradients different physical parameters to show the impact of the measurement.

Background Physics

The main equations governing the movement of plasma are *described by* gradients in both time and space. Gradients parallel to the ground in the high latitude region are of special importance due to the magnetic geometry of the area which drives the different phenomena. As one moves around the plane parallel to the ground different field lines are intersected. Some of these field lines could be conjugate with reconnection events while others are not. Another important aspect is how the plasma parameters are changing with time. It is important to disambiguate the spatial and temporal gradients to understand the physical process taking place.

ISR Image Formation Theory

Incoherent scatter radar uses the inherent random fluctuations of the plasma in the ionosphere to measure physical parameters. Most commonly measured is electron density, temperature and ion temperature. The sensor modality takes advantage of a physical model which ties together the plasma parameters and the frequency content of the fluctuations (Kudeki 2011).

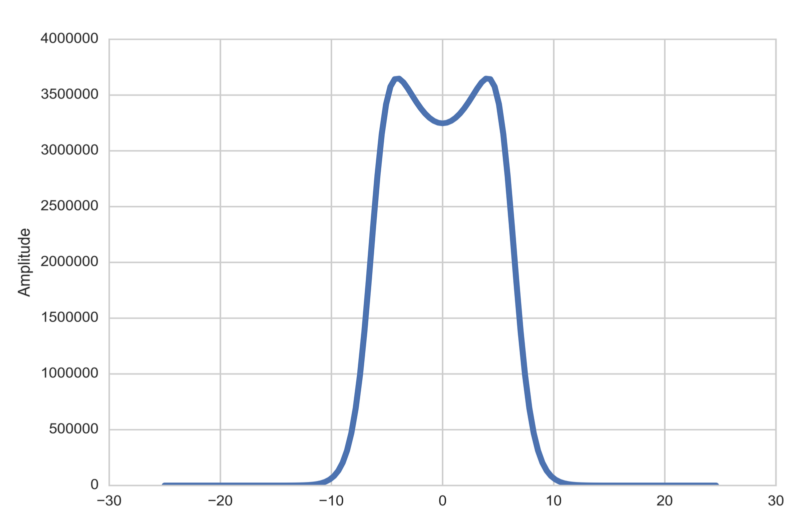
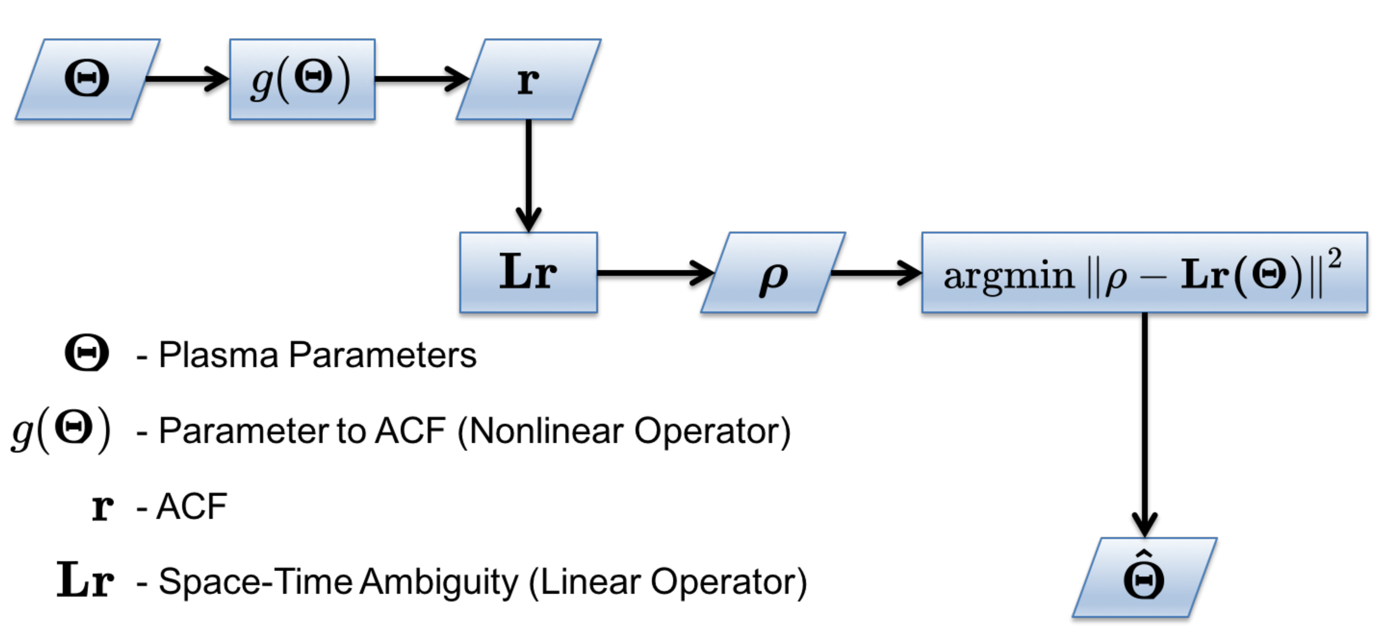


Figure 1: Example of spectrum of fluctuations. With N_e =1e11, $T_e = T_i$ = 2000k.

The first step in ISR is measure the frequency content, by performing an estimate of the autocorrelation of the return signal. In order to estimate this second order statistic averaging over both time and space are needed otherwise the measurement will be too noisy. This inherent averaging is referred to as a space-time ambiguity function (Swoboda, 2015), which blurs the ACF before it is fitted to a set of plasma parameters.



Θ - Plasma Parameters

$g(\Theta)$ - Parameter to ACF (Nonlinear Operator)

$\mathbf{r}$ - ACF

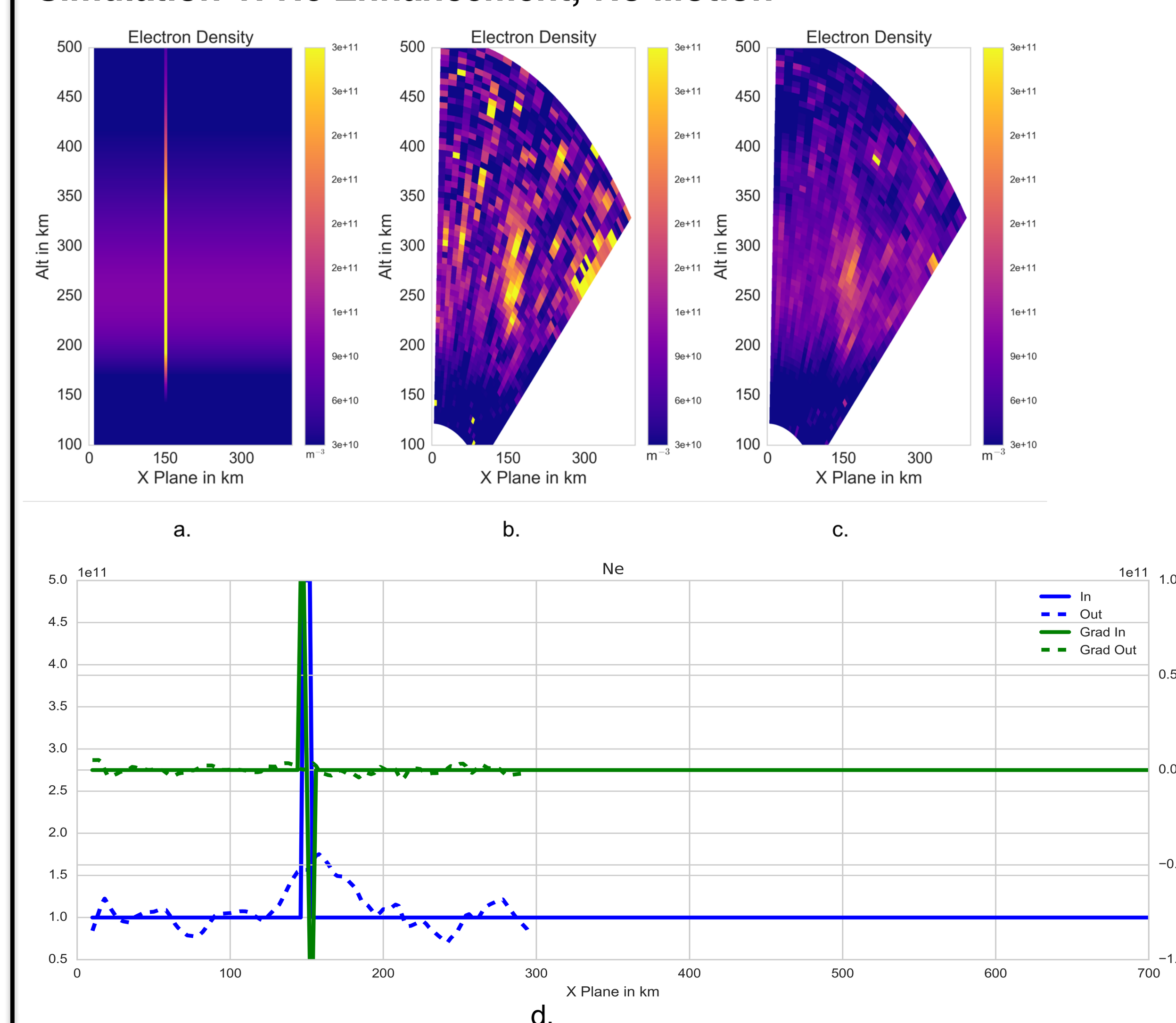
$\mathbf{Lr}$ - Space-Time Ambiguity (Linear Operator)

ρ - Blurred ACF

Figure 2: Block diagram of the measurement process in ISR.

Simulations

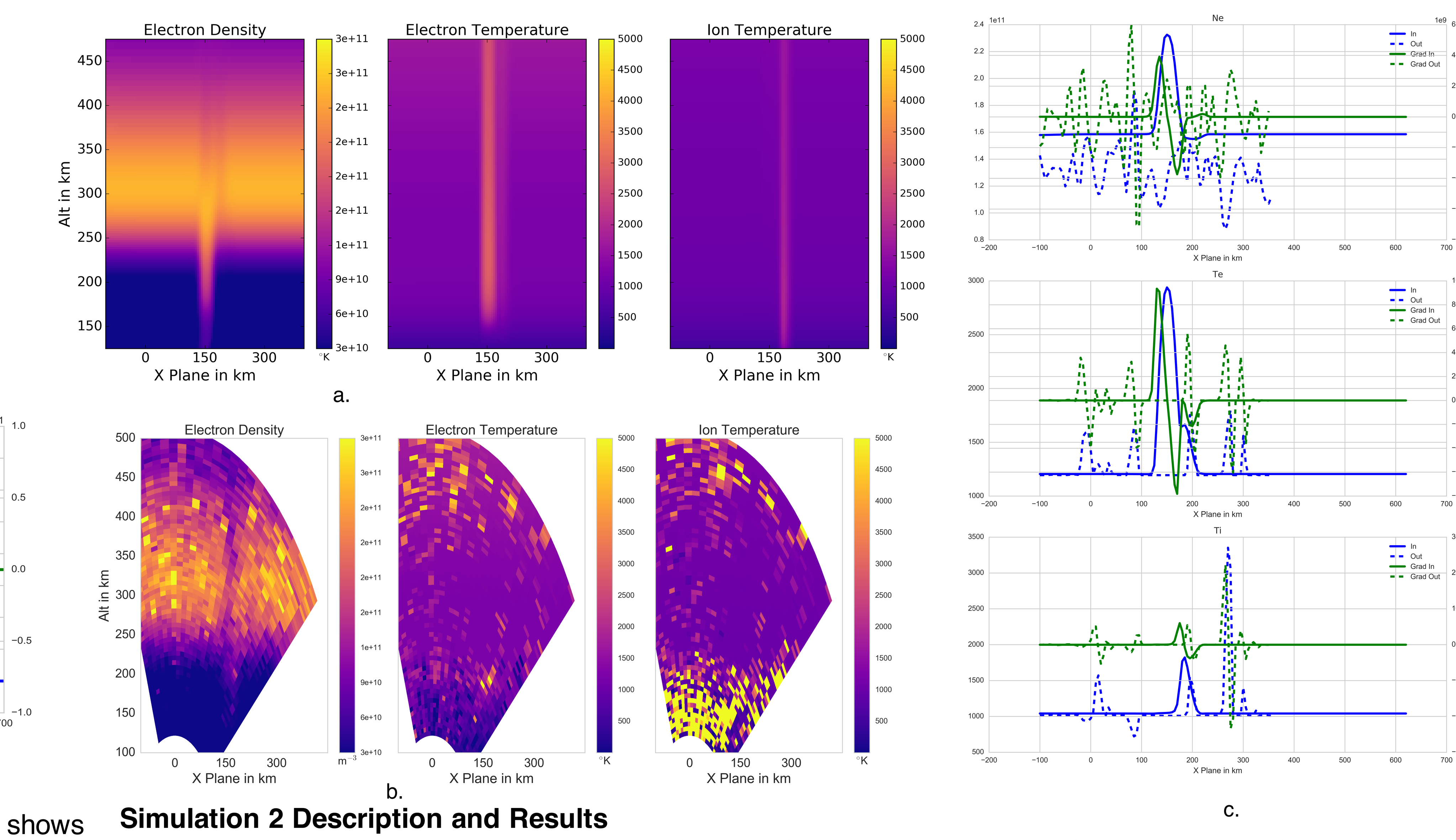
Simulation 1: Ne Enhancement, No Motion



Simulation 1 Description and Results

The simulation has single electron density enhancement. Panel a shows the input electron density data. Panels b and c show the measured electron density from the simulation with 15 second integration and 60 integration (60 and 240 pulses per position). Panel d. shows a cross section of the electron density at an altitude of 250 km from the 60 second integration and its gradient. The image is noisy but a large jump in the electron density can be see in the fitted example and seems to be visible.

Simulation 2: Multi-Fluid Model of Field Aligned Current



Simulation 2 Description and Results

The simulation uses as input data the result of a multi-fluid ionosphere model (Zettergren, 2008). The data shows the result of a field align current removing electron density from the ionosphere and is taken from Perry, 2015. The ISR system is integrating over 60 seconds or 255 pulses per position. Panel a shows the input, while panel b shows the results of the ISR simulation and lastly panel c shows the parameters and their gradients parallel to the ground at 250 km altitude The result is rather noisy for the electron density an the gradient is hard to pick out. The enhancement in electron temperature does not seem to be visible. There is a small enhancement in ion temperature and it does seem visible in the in the 250 km cut away.

ISR Simulation

The ISR simulator can create low level IQ data. From this data ACF can be estimated and then fit to parameters. The simulator creates filters using ISR spectra and from there uses them to shape complex white Gaussian noise at each point in space. The pulse shape then windows the data and it weighted and summed accordingly with the signals from other points in space.

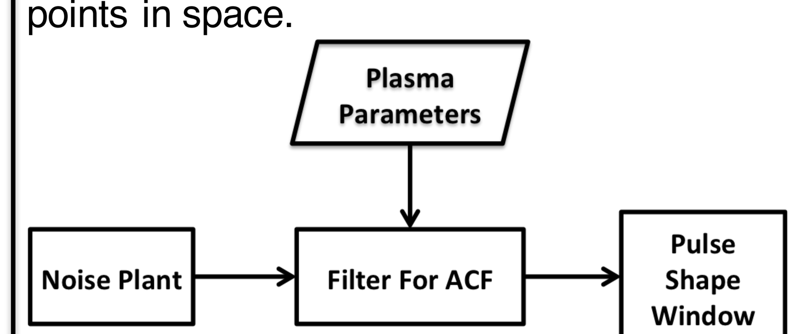


Figure 3: The core filter structure at each point in time and space.

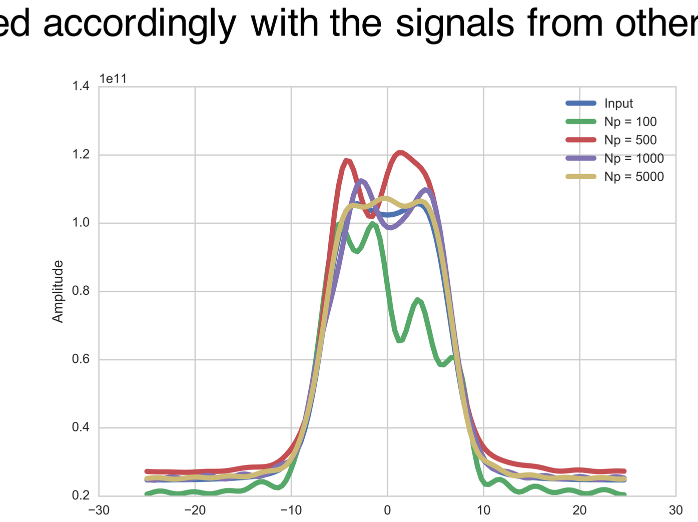


Figure 4: Example spectra showing the convergence as more pulses are integrated.

Once the data has been created it is then sent through a standard long pulse processing chain. The first step in the processing is to estimate the ACF and then fit to that to a set of plasma parameters.

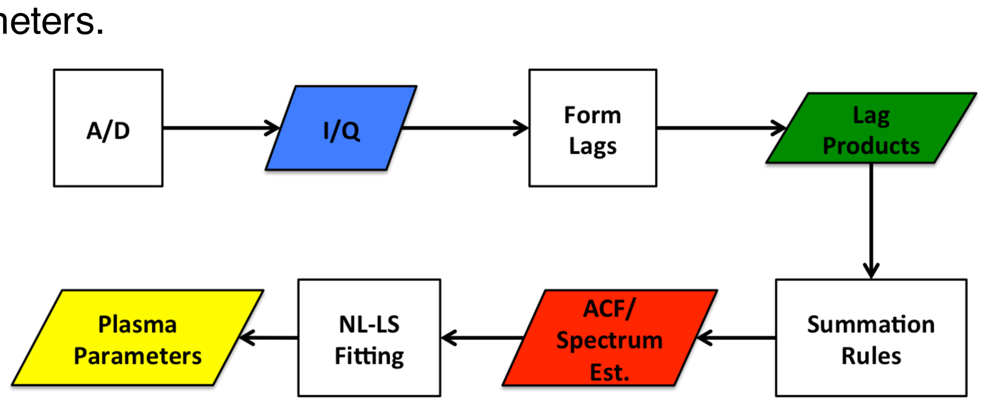


Figure 5: A flow chart of the processing for ISR data in using a long pulse waveform.

References

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Future Work

Better understanding of ISR image formation can ultimately help understand the underlying physics that are being observed. The ISR simulator will continue to be developed. We believe it can be used in a number of ways in a number of ways

- Using the simulator to design experiments
- Input multiple types of phenomena to determine what type of ambiguities may occur during the experiment.

We are also pursuing a number of avenues to improve the resolution of these gradients

- Using inverse theory to undo the effect of the space-time ambiguity operator on the ACFs.
- Using information from other sensors to help remove ambiguities from the ISR alone.

Conclusion

We have shown through simulation the impacts of the ISR processing chain. The ISR processing can impact the measurement of gradients of the plasma parameters adding errors in a number of ways. This simulator can also be used in future experiments to understand this type of processing on a number of different phenomena.