Updating the full-profile incoherent scatter analysis at Jicamarca

D. L. Hysell[1] *and M. A. Milla*[2]

[1]Cornell University, 2122 Snee Hall, Ithaca, NY, USA, (david.hysell@cornell.edu)

[2]Jicamarca Radio Observatory, Lima, Perú, (marco.milla@jro.igp.gob.pe)

Abstract

A full-profile incoherent scatter analysis, in which all ionospheric state variables at all altitudes are estimated simultaneously, has been implemented at Jicamarca for topside research. Such an analysis is particularly expedient at Jicamarca where the correlation time of the 50-MHz echoes is long. Long pulses are interleaved with short double pulses which provide complementary measurements at altitudes below and near the F peak. Absolute number density calibration is performed by exploiting Faraday rotation. We compute range-lag ambiguity functions for lag profile forward modeling in a general way. Autocorrelation function calculations take into account the small magnetic aspect angles of Jicamarca observations. Regularization is used to confine the solution space of the analysis and confer stability. A grid search provides the initial state for the iterative method we use. The overall algorithm can be made to run in real time on a single i7 processor core. Representative data are used to demonstrate the efficacy of the algorithm.

1. Introduction

For much of its history, Jicamarca employed a double-pulse technique for incoherent scatter experiments [1, 9]. Pairs of short pulses with opposing circular polarizations were transmitted, and lag product matrices were assembled from the backscatter, one lag at a time. The double pulse experiment is relatively immune to clutter from the ground, the equatorial electrojet, and space debris and remains the only viable option for measuring incoherent scatter spectra in the valley-region and bottomside using antenna pointing positions with large magnetic aspect angles. It also provides a means of absolute calibration through the exploitation of Faraday rotation.

About 15 years ago, the double-pulse began to be interleaved with a randomized alternating coded pulse for ISR probing near and above the *F* peak [5, 6, 7, 3] The alternating code provided multiple lag product estimates from each pulse and more fully utilized the available duty cycle of the transmitters. The data quality was sufficiently good to permit fitting either the electron-ion temperature ratio or the hydrogen ion fraction near the *F* peak and in the topside, although generally not both simultaneously. Unlike the double-pulse mode, this mode requires the consideration off-diagonal terms in the error covariance matrix when performing range-gated parameter fitting.

Subsequently, uncoded long pulses were introduced to the mode in concert with a full-profile analysis procedure [5, 2, 8, 4]. This procedure involves the simultaneous estimation of state parameter profiles directly from all the measured lag products. The technique belongs to a class of problems in statistical inverse theory. The mode and the analysis offer improved performance compared to the the alternating coded pulse experiment in many instances due the a reduction in self clutter. It is generally possible to fit for electron and ion temperature as well as hydrogen and helium ion fractions continuously throughout the topside. The analysis is complicated and computationally demanding, however. Practical implementation requires expedient methodology.

2. Methods

The following list itemizes the main components of the full-profile analysis methodology currently employed at Jicamarca:

- The electron density, electron and ion temperatures, and H^+ and He^+ abundances are expressed using parametrizations involving cubic B-splines.
- Range-lag ambiguity functions are computed based on the characteristics of the transmitter pulse and the receiver filter impulse response function. Tables of samples and weights for numerical quadrature are calculated once at the start of the analysis based on these ambiguity functions.
- Redundancy in the computation of theoretical autocorrelation functions is minimized.

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

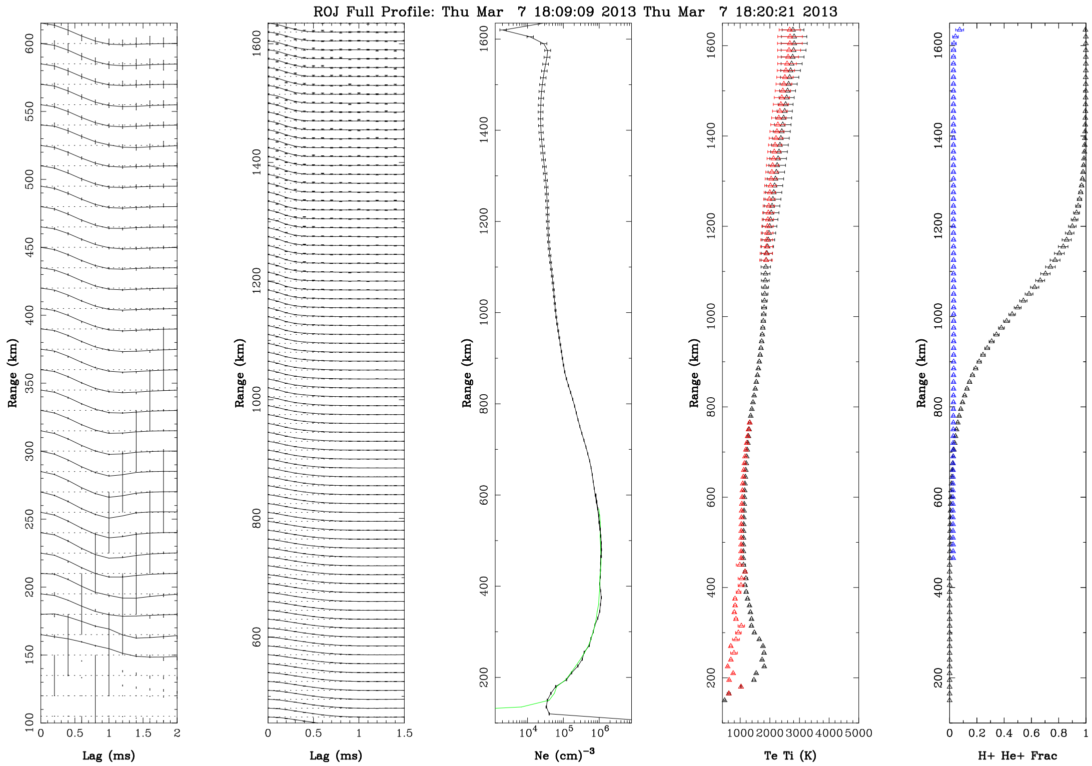

Figure 1: Representative results from full-profile analysis. From left to right, the panels show double-pulse autocorrelation functions, long-pulse lag profiles, electron density, electron (black) and ion (red) temperature, and hydrogen (black) and helium (blue) ion fraction.

- Regularization is used to limit the candidate solution space and confer stability. The roughness of the state parameters as well as certain other nonphysical conditions (e.g. T_i¿T_e) are penalized.
- A grid search is used to identify a suitable initial guess for iterative solution, which is based on a weighted damped nonlinear least squares approach.
- ISR theory for small magnetic aspect angles is utilized, and provisions for considering the variation of the magnetic aspect angle across the radar beam are provided.
- Data from the double- and long-pulses are merged seamlessly.

3. Findings

Representative results from the complete full-profile analysis are shown in Fig. 1. The results in this case are based on approximately 10 min. of integrated data. Contamination from space debris has been removed using an algorithm based on order statistics. As is typically the case, the final χ-squared parameter normalized by the number of data elements is approximately unity.

Long-pulse data have been acquired at Jicamarca routinely for approximately the last 20 years. Efforts are underway to reprocess the data using the new analysis scheme. We are also endeavoring to validate the measurements against satellite measurements when possible and against models such as SAMI2-PE [10], which considers the effects of energetic electron transport (which are especially important around sunrise). It was important to develop a computationally efficient methodology before undertaking the reprocessing. The present approach runs faster than real time on a single i7 core and is readily parallelizable.

References

[1] D. T. Farley. Incoherent scatter correlation function measurements. *Radio Sci.*, 4:935–953, 1969.

[2] J. M. Holt, D. A. Rhoda, D. Tetenbaum, and A. P. van Eyken. Optimal analysis of incoherent scatter radar data. *Radio Sci.*, 27:435–447, 1992.

[3] D. L. Hysell. Incoherent scatter experiments at Jicamarca using alternating codes. *Radio Sci.*, 35:1425–1436, 2000.

[4] D. L. Hysell, F. S. Rodrigues, J. L. Chau, and J. D. Huba. Full profile incoherent scatter analysis at Jicamarca. *Ann. Geophys.*, 26:59–75, 2008.

[5] M. S. Lehtinen. Statistical theory of incoherent scatter radar measurements. Technical Report 86/45, Eur. Incoherent Scatter Sci. Assoc., Kiruna, Sweden, 1986.

[6] M. S. Lehtinen and I Häggström. A new modulation principle for incoherent scatter measurements. *Radio Sci.*, 22:625–634, 1987.

[7] M. S. Lehtinen and A. Huuskonen. General incoherent scatter analysis and GUISDAP. *J. Atmos. Terr. Phys.*, 58:435–452, 1996.

[8] M. S. Lehtinen, A. Huuskonen, and J. Pirttilä. First experiences of full-profile analysis with GUISDAP. *Ann. Geophys.*, 14(12):1487–1495, 1996.

[9] J. E. Pingree. *Incoherent scatter measurements and inferred energy fluxes in the equarotial* F-*region ionosphere*. PhD thesis, Cornell Univ., Ithaca, N. Y., 1990.

[10] R. H. Varney, W.E. Swartz, D.L. Hysell, and J.D. Huba. SAMI2-PE: A model of the ionosphere including multi-stream interhemispheric photoelectron transport. *J. Geophys. Res.*, 117(A06322):DOI: 10.1029/2011JA017280, 2012.