IDA3D: An Ionospheric Data Assimilative Three Dimensional Tomography Processor

Dr. Gary S. Bust
Applied Research Laboratories, The University of Texas at Austin
10000 Burnet
Austin Texas 78758
phone: 512-835-3623 fax: 512-835-3808 email: gbust@arlut.utexas.edu

Award Number: N00014-97-1-0236
http://www.sgl.arlut.utexas.edu/cir/

LONG-TERM GOALS

One long-term goal of this research program is to develop an operational ionospheric electron density tomography processor with the following characteristics:

1. Solve for electron density on a global grid and adapt the resolution of the grid based on the data coverage

2. Be capable of processing data over a long time period, with either regular or varying sample times based on data availability.

3. Accept multiple sources of data from both ground and space based sources

4. The output electron density can be directly ingested into ionospheric data assimilation models.

5. Be able to accept as input, ionospheric data assimilative model inputs to initialize the tomography inversion.

6. Be capable of running in near real-time in a completely automated manner

The last year of research has resulted in an initial version of our tomography processor, ionospheric data assimilation 3D (IDA3D), which has partially fulfilled the long-term goals stated above.

A second long-term goal of this research has been to validate our tomography inversion algorithms in the field with real data and independent data from incoherent scatter radars (ISR) and ionosondes. Our work in the last year, as well as research conducted by other tomography investigators such as the research group from the University of Wales and from Northwest Research Associates has essentially demonstrated the validity of tomographic mapping of the ionosphere in mid-latitudes, low-latitudes and high-latitudes. We feel now, that this long-term goal has been met.

The third long-term goal of this research is to apply our tomography processor results to scientific analysis, investigation and interpretation of the dynamic ionosphere. During the last two years we have conducted experiments in the Caribbean, Greenland and Alaska. We have contributed several

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **IDA3D: An Ionospheric Data Assimilative Three Dimensional Tomography Processor**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Applied Research Laboratories,,The University of Texas at Austin,10000 Burnet,,Austin,,TX, 78758**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

presentations and scientific papers on the interpretation of the dynamic ionosphere from tomographic results, and we anticipate continuing that work over the next three years.

OBJECTIVES

The first technical objective of this research was to develop and test a regional three-dimensional tomography algorithm that would be suitable for data assimilative models. The requirements on the algorithm were that it be able to accept beacon satellite TEC data as well as ground GPS TEC data and ionosonde data, and that it use as little ad-hoc *a priori* information as possible.

Because we required the algorithm to be suitable for data assimilative models, it needed to be able to make an estimate of the accuracy of the electron densities obtained from the inversion. In addition, since the algorithm would apply over a three-dimensional region, it was necessary that where data did not provide information, that the output of the algorithm be self-consistent with the data assimilative model inputs.

Finally, in order to meet our long-term goals, the algorithm had to be designed in such a manner that it could be extended to a global grid and to other data sources.

The second technical objective was to field tomography receivers, collect data, process it with the tomography algorithm and perform scientific analysis on the results.

APPROACH

The approach adopted here, was to borrow from the research and development already conducted over many years by the atmospheric weather community. In particular, the concept of an “objective analysis” on a set of data, resulting in an “analyzed state variable” was adopted. In essence, adopting this overall concept allowed us to generalize beyond the concept of “tomographic inversion algorithms” to the concept of providing the very best analysis of a model state variable, given an initial model prediction and a set of data. In addition, adopting the objective analysis framework, and specifically the framework of 3DVAR articulated by NRL West ([1],[2]) allowed us to make us of an extensive set of existing literature regarding the fusing of different data types, the effects of data types on the analyzed state variables and given the analysis the re-initialization of all of the model state variables and the next cycle of model predictions.

The algorithm we have based IDA3D on is the 3DVAR algorithm of NRL West. These algorithms are statistical minimization algorithms (optimal minimization if the covariance matrices are known exactly), and one of the benefits of such algorithms is they provide a formal measured of the analyzed error, given the initial model prediction error.

In terms of meeting the scientific analysis objective, coherent ionospheric Doppler receivers (CIDRs) developed here at ARL:UT have been deployed to the Caribbean for two combined ionospheric campaigns (CIC) and to Greenland and Alaska for extended, multiple-year long-term monitoring campaigns.

WORK COMPLETED

The IDA3D algorithm has been developed in the IDL language, tested and used on real data from deployed arrays. Following is a list of the current tested capabilities of IDA3D:

1. A 3D regional uniform or regular grid. The user can input separate arrays of latitudes, longitudes and altitudes, or can specify the start and end points and spacing for each dimension.

2. The algorithm can run on a single set of data for a given time, or it can be run sequentially over many days worth of data.

3. The algorithm can use previous results to initialize the next inversion using a Kalman filter approach, or it can process each inversion separately using a climatalogical model such as IRI95 [3] as the initialization.

4. The algorithm accepts beacon TEC data, GPS ground TEC data, ionosonde and ISR data as inputs.

5. The algorithm uses a Gaussian correlation model for spatial correlations of the background model.

6. The algorithm outputs the analyzed electron density on the specified grid as well as the analyzed variance on the electron density.

7. The algorithm has been run in near real-time on test data downloaded from the Greenland array.

Processing, inversion, scientific analysis and interpretation has been completed on data sets from the Caribbean, Greenland and Alaska. In addition, older data sets from mid-latitudes investigating ionospheric storms have been applied to IDA3D and new analysis performed. The results of these investigations have been presented at several conferences and three archival papers have been published.

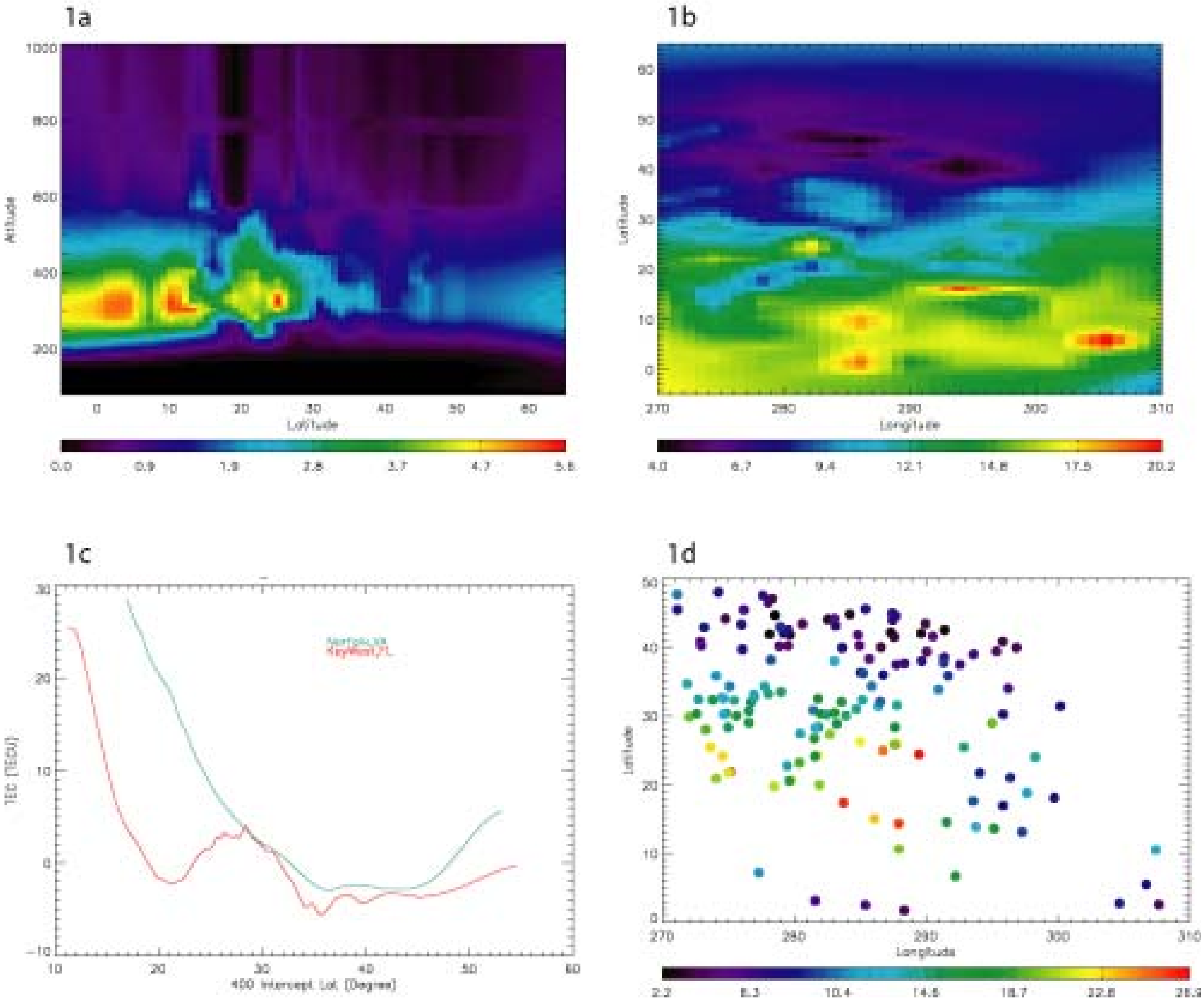

Figure 1: Four images of ionospheric structure in the Caribbean. The upper left shows a 2D image (latitude versus altitude) of electron density from the tomographic processor. The upper right shows an image of vertical TEC (longitude versus latitude) for the same data set. The lower left shows a plot of data from two CIT receivers that went into the inversion, while the lower right show the GPS slant TEC data that went into the inversion.

RESULTS

1. CIC1: For this experimental campaign, a suite of instruments, by many researchers were deployed in and around Puerto Rico. We contributed tomography receivers in several locations, and also analyzed a large set of GPS stations from throughout the region. The primary result of interest from the campaign was the imaging by the all sky camera of the so-called mid-latitude turbulent depletions [4]. Figure 1 above, shows results from our tomographic and GPS analysis.

2. CIC2: Was very similar to CIC1 in design and analysis. Our primary result was to compare our IDA3D results; using both beacon TEC and GPS TEC with results from the Utah State

University (USU) ionospheric predictive model as well as from the JPL GPS based TEC maps. Figures 2 and show comparisons between IDA3D and the JPL TEC maps.

3. Initial Greenland Analysis: Figure 4 shows an inversion from the Greenland array with an Auroral-E feature. The feature has been confirmed by an ionosonde at Narsarsauq. This is important, since if tomography can reliably and accurately image E-region electron densities, it can contribute important spatial and temporal information to the Joule heating at high latitudes.

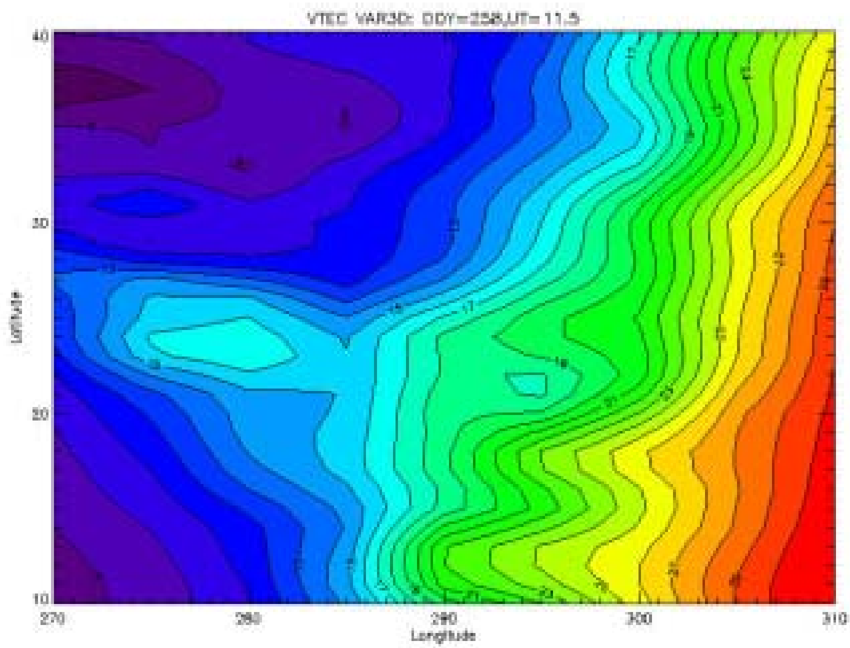

Figure 2: 2D image (longitude versus latitude) of VTEC from IDA3D processor

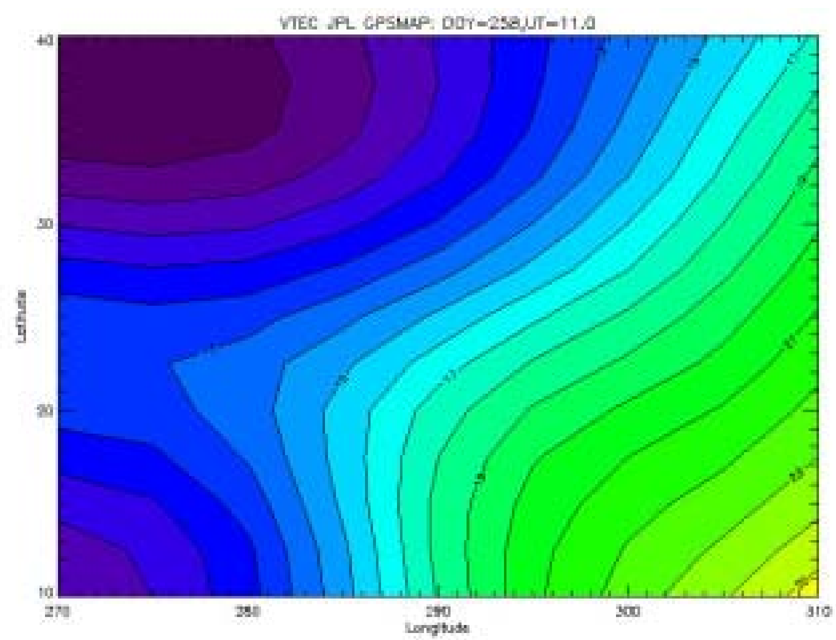

Figure 3: Same region as Figures 2 and 3. VTEC from JPL GPS TEC maps

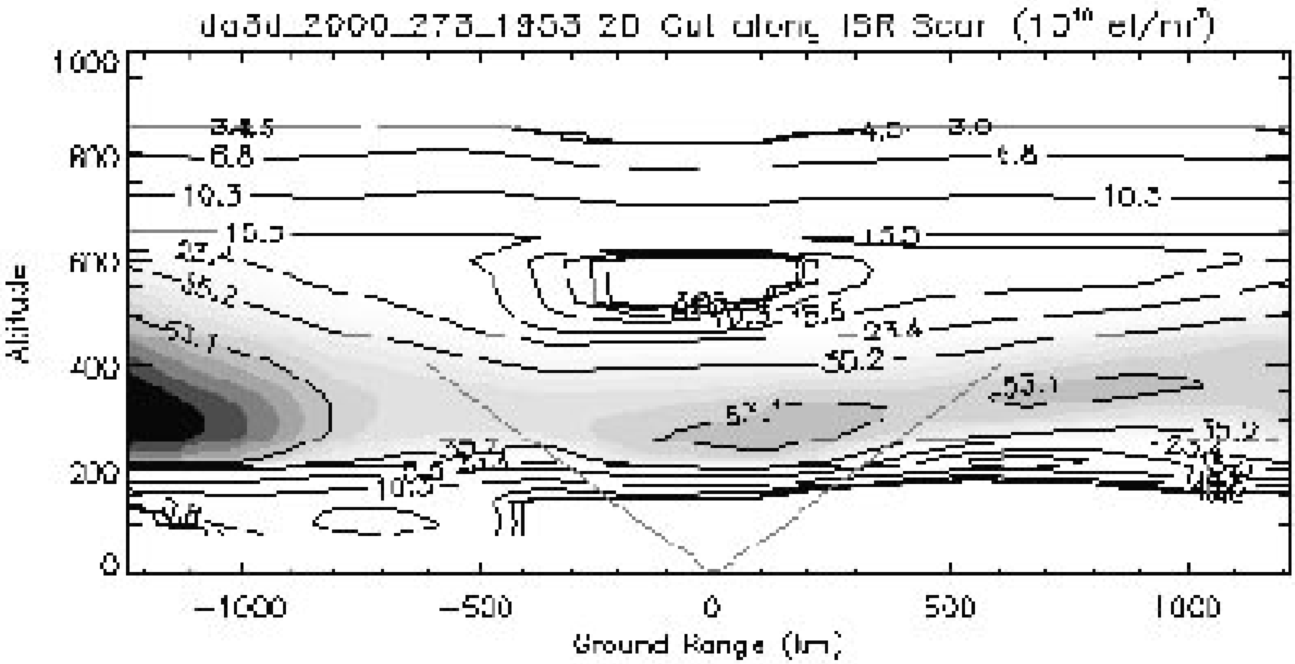

Figure 4: Greenland Reconstruction along scanning meridian of Sondestrom ISR Note the E-region structure near –600 km. This structure was confirmed by an ionosonde at Narsarsuaq

IMPACT/APPLICATIONS

This research impacts both space weather modeling, estimation and prediction and the propagation of RF signals through the upper atmosphere. Relevant applications include RF communication and navigation systems, RF geo-location systems, and HF or VHF radar systems that can be effected by the ionosphere.

TRANSITIONS

None

RELATED PROJECTS

- NSF Greenland: This NSF project focuses on using the Greenland tomography data with IDA3D to investigate E-region electron densities and the related Joule heating effects.

- Alaska Tomography: This project in collaboration with the Geophysical Institute at the University of Alaska Fairbanks and Northwest Research Associates is designed for long term monitoring of the Alaska ionosphere in support of HAARP activities and to do scientific studies of neutral wind coupling to the ionosphere in the Fairbanks region.

- Millstone Hill Tomography Array: This project is sponsored by AFOSR through the DURIP program and will result in the deployment of 5 new CIDR receivers along an array extending from Block Island Mass. north into Canada, and along a meridian coincident with the Millstone Hill ISR.

In collaboration with Millstone Hill we expect to develop as part of the Millstone Hill standard scheduling software, a real-time scheduler for IDA3D.

- NIWA Data Assimilation: This is currently a small project, that we hope will grow, designed to couple IDA3D, ICS with a fairly simple data assimilative model. The result will support specific RF applications of interest to NIWA, and the current plan is to use the SAMI2 [7] publicly available predictive model for assimilation.

REFERENCES

1. R. Daley, and E. Barker, "The NRL 3DVAR Source Book", NRL internal report, Naval Research Laboratory, Monterey, CA., 1998

2. Roger Daley, Atmospheric Data Analysis, Cambridge Atmospheric and Space Science Series, Cambridge University Press, Cambridge

3. D. Bilitza, K. Rawer, L. Bossy, and T. Gulyaeva, "International Reference Ionosphere – Past, Present, Future", Adv. Space Res., 13, 3-23, 1993

4. G.S. Bust, D. Coco and J. Makela, "Combined Ionospheric Campaign 1: Ionospheric Tomography and GPS total electron count (TEC) Depletions", 27(18) Geophys. Res. Lett., 2000

PUBLICATIONS

There were three archival publications under this research grant, as well as several publications in proceedings. In addition, there were a large number of presentations at conferences such as AGU, URSI and CEDAR. However, only the archival publications are referenced below.

1. G.S. Bust, D. Coco and J. Makela, "Combined Ionospheric Campaign 1: Ionospheric Tomography and GPS total electron count (TEC) Depletions", 27(18) Geophys. Res. Lett., 2000

2. G.S. Bust, C. Coker, D. Coco, T.L. Gaussiran II and T. Lauderdale, "IRI Data Ingestion and Ionospheric Tomography", 27(1) Adv. Space Res., 2001

3. G.S. Bust, D. Coco, and T.L. Gaussiran II, "Computerized Ionospheric Tomography Analysis of the Combined Ionospheric Campaign", *accepted* Radio Science, 2001

PATENTS

None.