# Enhanced Use of GPS and Airglow Data for Fusion into an Ionospheric Specification and Radio Propagation Model

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## LONG-TERM GOALS

Our long-term goal is to develop a processor for assimilation of GPS, UV airglow, and other data types for the purpose of near-real-time Internet dissemination of regional and, eventually, global ionospheric specification. Of particular interest are the electron density vs. height profiles (EDPs), determined with sufficient precision to meet ionospheric compensation requirements for future high-performance radio systems.

## OBJECTIVES

The first objective for this fiscal year is to further refine our techniques for converting two-frequency GPS receiver data into EDPs. The second objective is to determine how UV airglow data can be used with the GPS data for precision determination of EDPs on a regional or global scale. The third objective is to assess the validity of present processing techniques for these data. The fourth objective is to help determine how the EDP solutions can be used, both for the development and operation of an assimilating theoretical ionospheric model, presently under development, and for rapid deployment to the high-performance radio system community.

## APPROACH

There are over 200 two-frequency GPS ground receivers worldwide in the IGS network, approximately 80 of which supply data in near-real-time (within one hour) over the Internet, which we can process for ionospheric specification and distribute in the form of regional EDPs on a worldwide scale. There also over a hundred CONUS stations in the CORS network that provide this service. However, GPS receivers are concentrated mostly in the Northern Hemisphere at midlatitudes in land areas. This leaves holes in the worldwide distribution, mainly over oceans, at high and low latitudes, and in the Southern Hemisphere. On the other hand, UV airglow sensor data has become available and more such sensor systems are forthcoming. Presently, UV data from Earth limb-scanning satellite instruments are processed for determination of vertical oxygen ion density vs. height profiles (O+DPs). Models that include the ion distributions, such as IRI and the developing assimilating ionospheric (AIM) models, can be used to extract EDPs. Qualitative information about the maximum electron density (associated with the plasma frequency $f_oF_2$) and the height at maximum of the F layer (associated with height $h_mF_2$), as well as some shape characteristics, can be directly obtained from the O+DPs. Of particular importance, UV airglow data can be obtained over portions of the world where GPS data are scarce,

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14. ABSTRACT

**Our long-term goal is to develop a processor for assimilation of GPS, UV airglow, and other data types for the purpose of near-real-time Internet dissemination of regional and, eventually, global ionospheric specification. Of particular interest are the electron density vs. height profiles (EDPs), determined with sufficient precision to meet ionospheric compensation requirements for future high-performance radio systems.**

15. SUBJECT TERMS

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thus enabling global EDP specification through appropriate combination of GPS and UV airglow data systems, the details of which are being worked out by Geoloc in cooperation with NRL scientists.

The method for processing GPS data for slant TEC determinations for a system of GPS receivers is discussed in detail in a recent paper [Reilly and Singh, 2001]. We have further refined this technique for EDP determination as follows. Recall that shifted differential (L1–L2) phase pseudorange ($\boldsymbol{\Delta P}$) data (in meters) are used as a proxy for differential code pseudorange data, in order to minimize multipath effects and maximize precision. We assume that we have two hours of data from each of five satellites, which is sufficient to determine ITRAY (extension of RIBG) ionospheric model parameters and separate out the contribution of constant differential hardware biases. $\boldsymbol{\Delta P}$ is modeled in terms of ionospheric total electron content ($\boldsymbol{TEC}$) and the satellite-receiver differential hardware bias ($\boldsymbol{DB}$) as

$$\mathbf{9.5175(\Delta \boldsymbol{P}) = \boldsymbol{TEC}(SF2, SM3, SWDTH, CFAC, Kp) + \boldsymbol{DB}}$$

in TEC units (1 TECU = $10^{16}$ el/m$^2$), where we have listed the driving parameters of the ITRAY ionospheric model explicitly. Here, SF2 is a sunspot number that determines the maximum density of the F2 layer, SM3 is a sunspot number that determines the height at this maximum, SWDTH is a sunspot number that determines the width of the Chapman function for the F layers, and CFAC is a parameter that determines the falloff rate with height in the topside profile (above the maximum). Previously, we had determined only SF2 and used the default conditions: SF2 = SM3 = SWDTH and CFAC = 0.86. Now, for the sake of determining accurate EDPs, we are allowing all the aforementioned parameters to vary independently, within limits, in the least-squares fitting problem. As before, we are fixing the Kp parameter, which is a standard magnetic activity parameter, by determining it from available magnetometer data. Hence, there are nine model parameters to be determined from GPS data for five satellites, the previous four ionospheric model parameters and five DB values. This is a nonlinear, multiparameter model-fitting problem, which is solved by a standard approach for this problem type, the Levenberg-Marquardt Method, which is explained in Press et al, 1992.

A few months ago, NRL scientists processed nighttime UV airglow data from limb scans of the ARGOS satellite instrument for October, 2000. Sarah McDonald used an approach based on Ken Dymond's method to extract O+DPs at several locations, which were converted to EDPs through the IRI model. We compare these profiles with those obtained by processing time-coincident data from relatively nearby GPS receivers: one at Driver in Virginia with lat-lon coordinates [39.96, -76.56], one at Boulder in Colorado at [40.18, -104.73], and one in Hawaii at [21.98, -159.76]. This affords us the ability to-cross-check EDPs obtained from different sources and assess their validity relative to ground truth. The only ground truth data available for the time interval processed so far, Oct 8 to Oct. 14, 2000, is from digisondes at Wallops Island at [37.95, -75.47], which is near the Driver GPS receiver, and Boulder at [39.99, -105.26], which is near the Boulder GPS receiver. The former allows us to check values for maximum density and height, whereas the latter yields data only for the maximum density. There is no digisonde data available for Hawaii.

## 1. Test for validity of GPS-inferred EDPs near the GPS receiver

From Oct. 8 to Oct. 14 we processed two hours of data each day from five satellites at each of the GPS receivers at Driver, Boulder, and Hawaii in the intervals 0800-1000, 1000-1200, and 1200-1400 UT, respectively. These intervals were chosen for comparison with NRL's EDPs obtained from UV airglow data. We obtained the multiparameter fits, involving the ITRAY model and Levenberg-Marquardt method, as discussed above, and then used ITRAY to generate EDPs. To test validity, we used the Driver and Boulder GPS data to generate EDPs at the Wallops Island and Boulder digisonde locations and compared results to the digisonde solutions for maximum density and height at Wallops Island for the middle time of the associated time interval. The same was done for Boulder, except that the Boulder digisonde provides only the solution for the maximum density, but not for the height at maximum. Hence, there are fourteen cases, thus far, for comparison of the maximum density solutions and seven for comparison of the heights at maximum density. A few sample comparison cases are shown in Figures 1 and 2. The Wallops Island comparisons showed significantly closer agreement than the Boulder comparisons for maximum densities. Wallops Island maximum densities were within 20% with an average discrepancy of 7.0%. Boulder maximum densities were within 41% with an average discrepancy of 18.6%. Wallops Island heights at maximum were within 16% with an average discrepancy of 9.0%. At this stage of the investigation, these are encouraging numbers for the validity of GPS processing to obtain EDPs. Comparisons with incoherent scatter radar EDPs will be carried out in the future.

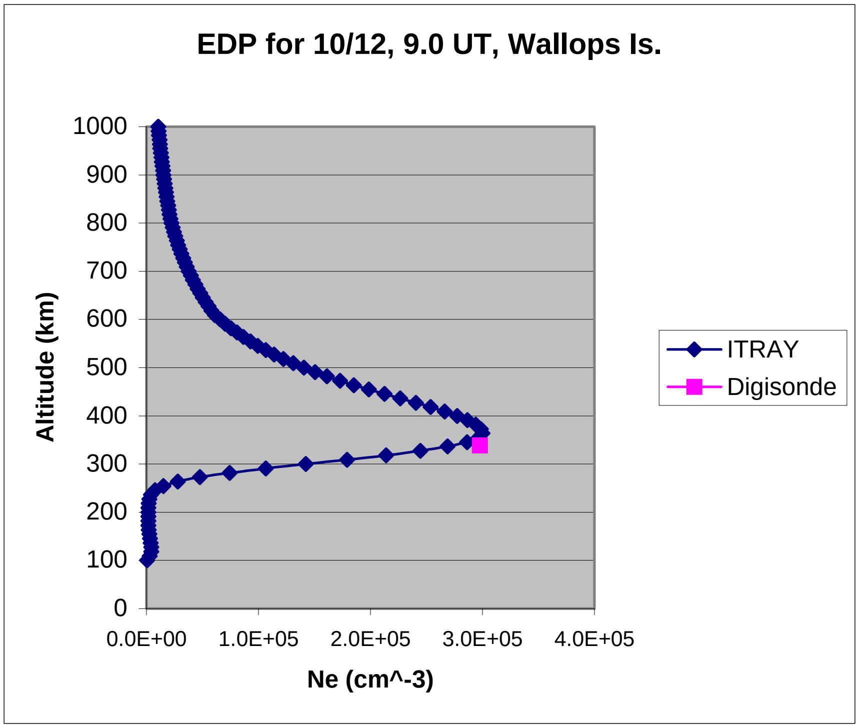

***Figure 1. Comparison of Driver GPS-inferred EDP with Wallops Is digisonde solution for maximum density and height at 0900 UT on 10/12/2000***

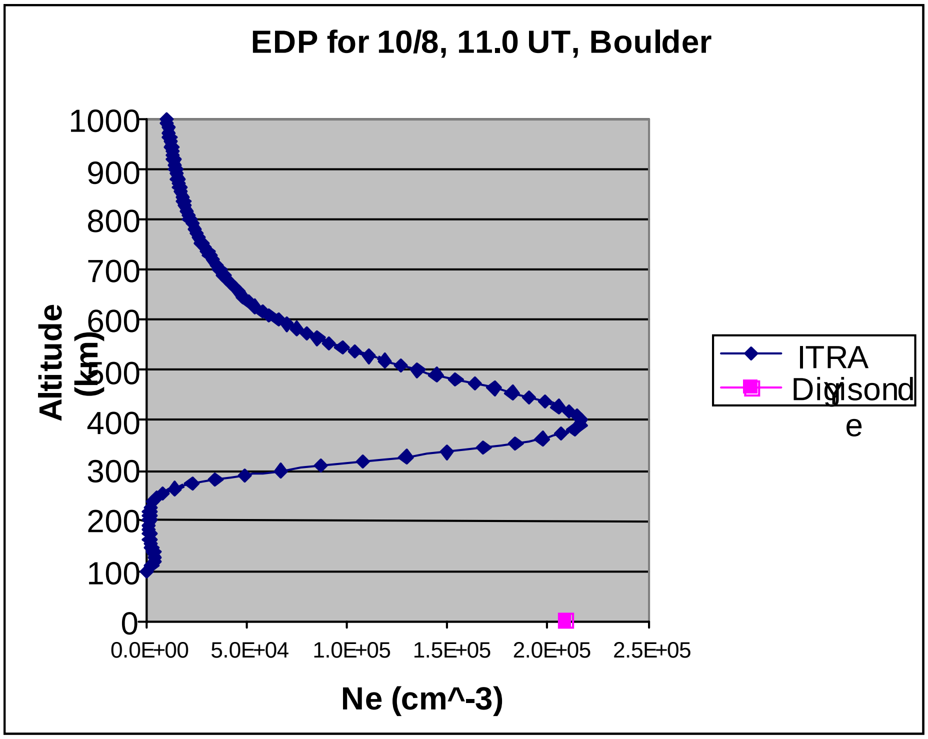

***Figure 2. Comparison of Boulder GPS-inferred EDP with Boulder digisonde solution for maximum density at 1100 UT on 10/12/2000***

## 2. Compare EDPs inferred from GPS and UV Airglow with Digisonde data

We have carried out 20 comparisons of GPS and UV airglow EDPs between 10/8/2000 and 10/14/2000. The process is to obtain driving parameters of ITRAY from the three aforementioned GPS receivers and then use these driving parameters in ITRAY for generation of the EDPs at the times and locations of the UV airglow EDPs. We use the driving parameter associated with the GPS receiver data that is closest in space and time to the UV airglow determination. We also include IRI EDPs for comparison, as well as EDPs obtained from RIBG, where we only allow SF2 to vary in the ionospheric model. These profiles are labeled by RIBG, whereas the EDPs from the multiparameter fits of ITRAY to GPS data are labeled by ITRAY. In many cases, when we have digisonde data that are reasonably close in space and time, we include it for comparison. We also looked at the possibility of including TOPEX and incoherent scatter radar for this period, but such data are not available for locations and times that are reasonably close to the UV airglow data considered in this report. Of the twenty cases we include six, the first three for 10/11/2000 and the second three for 10/14/2000 in Figures 6-8. These figures are representative of the other 14, relative to the points we wish to make next.

Figures 3-8 show a linear density scale, as opposed to the traditional log scale. As a result, the differences between profiles are more noticeable than usual. First, we note that the discrepancy between RIBG and ITRAY profiles illustrates the importance of allowing all the profile driving parameters to vary in the fitting process. Second, the digisonde data indicate that the ITRAY solution for maximum density and height is not far off and to the extent that the other profiles are far off from this data, those profiles are suspect. Hence, RIBG is suspect in Figure 4, IRI and UV are suspect in

Figure 6, and UV is suspect in Figure 7. Further, to the extent that the maximum density of an EDP differs greatly from ITRAY, if we believe the magnitude of errors we found in the discussion of Figures 1 and 2, then that EDP is again suspect. Hence, additional suspect profiles are UV and RIBG in Figure 5, UV in Figure 7, and both UV and RIBG in Figure 8. Hence, it appears that more work is needed to get reliable UV profiles and that IRI is occasionally unreliable. Further, for the purpose of obtaining EDPs, the one parameter model in RIBG is not sufficiently accurate. However, we do not mean to infer at this point that ITRAY EDPs are sufficiently accurate for all applications. Much more data, including ground-truth incoherent scatter radar and digisonde data, need to be analyzed first and related to particular applications. The shapes of the ITRAY EDPs are as yet untested by independent ground truth data, such as the incoherent scatter data.

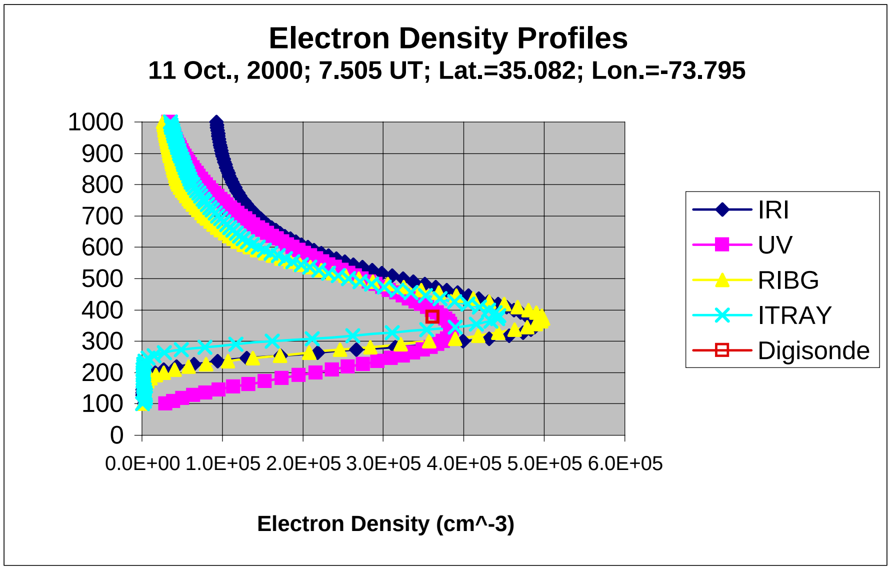

***Figure 3. EDPs from IRI, RIBG, ITRAY and UV airglow data, compared with Wallops Island digisonde data for 10/11/2000, 7.505 UT, lat 35.082, lon –73.795. Driver GPS data is used for RIBG and ITRAY***

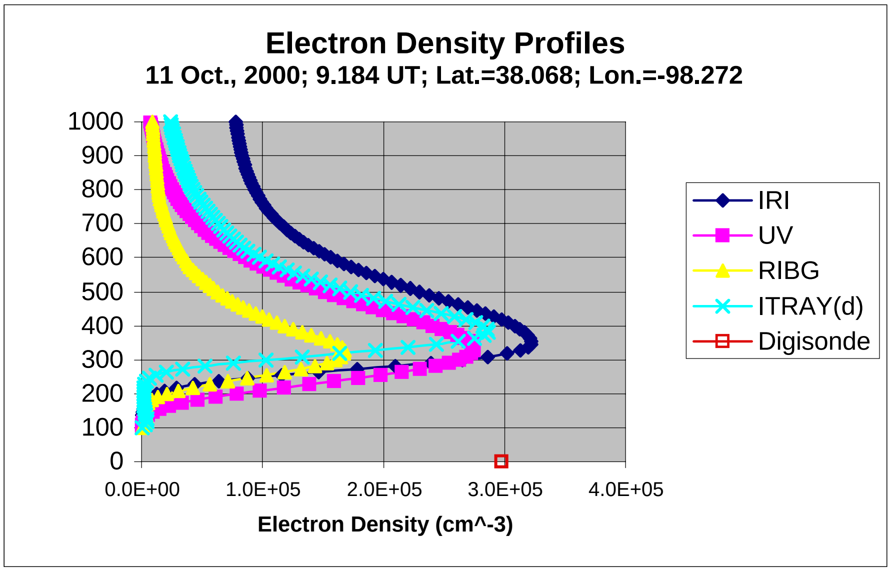

*Figure 4. EDPs from IRI, RIBG, ITRAY and UV airglow data, compared with Boulder digisonde data for 10/11/2000, 7.505 UT, lat 35.082, lon –73.795. Driver GPS data is used for RIBG and ITRAY*

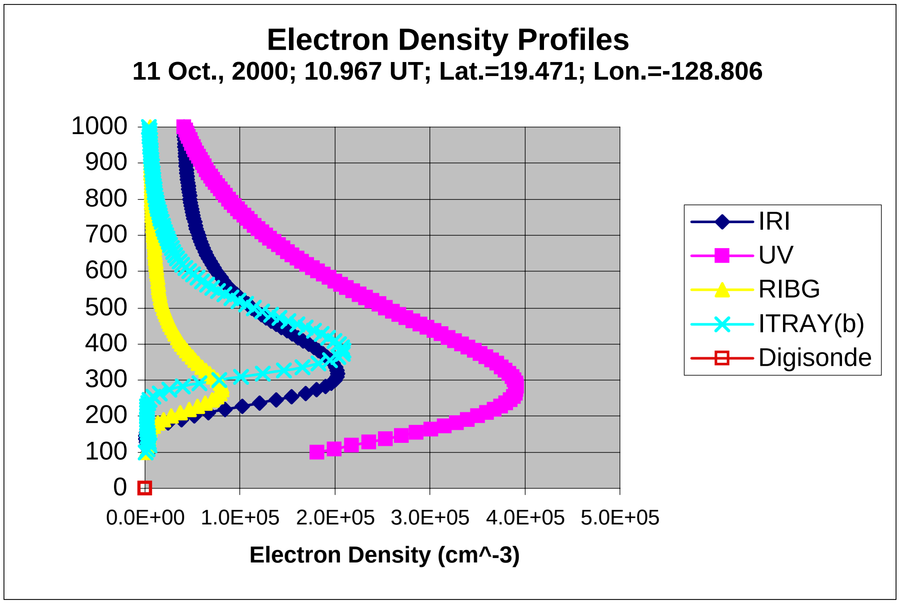

*Figure 5. EDPs from IRI, RIBG, ITRAY and UV airglow data, no digisonde data for 10/11/2000, 10.967 UT, lat 19.471, lon –128.806. Hawaii GPS data is used for RIBG and ITRAY.*

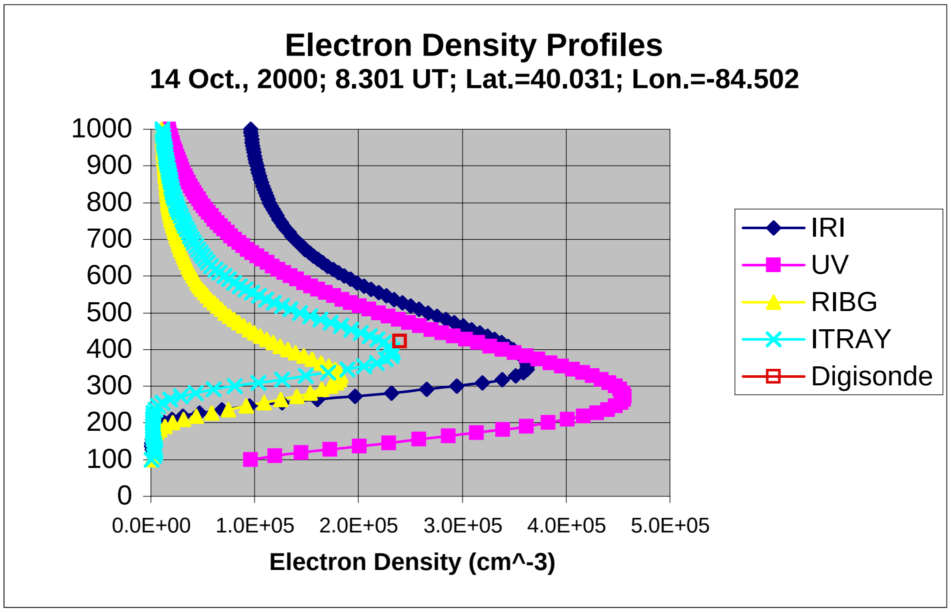

*Figure 6. EDPs from IRI, RIBG, ITRAY and UV airglow data, compared with Wallops Island digisonde data for 10/14/2000, 8.301 UT, lat 40.031, lon –84.502. Driver GPS data is used for RIBG and ITRAY*

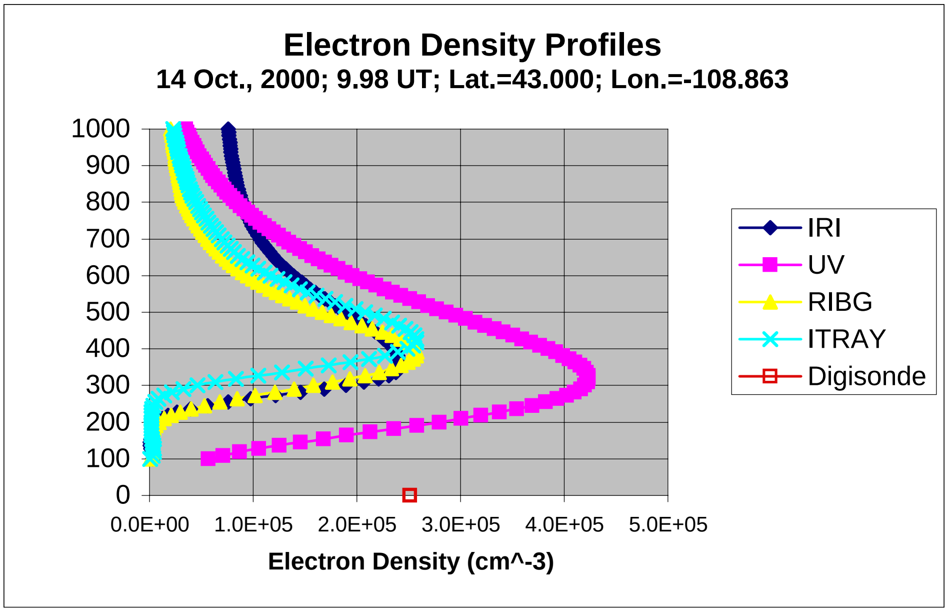

*Figure 7. EDPs from IRI, RIBG, ITRAY and UV airglow data, compared with Boulder digisonde data for 10/14/2000, 9.98 UT, lat 43.00, lon –108.86. Boulder GPS data is used for RIBG and ITRAY*

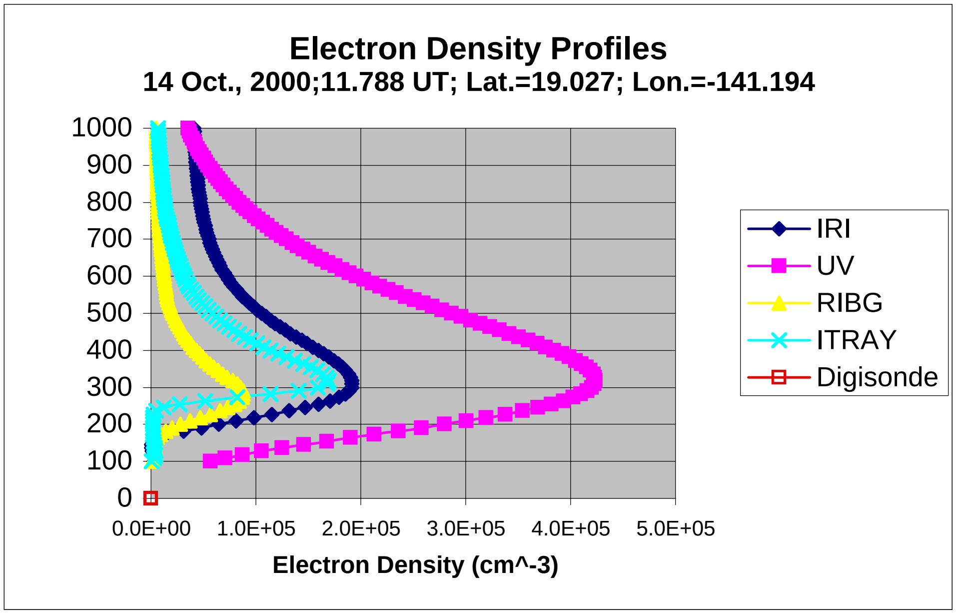

***Figure 8. EDPs from IRI, RIBG, ITRAY and UV airglow data, no digisonde data for 10/14/2000, 11.788 UT, lat 19.027, lon –141.194. Hawaii GPS data is used for RIBG and ITRAY.***

## WORK COMPLETED

In FY01, we have extended the techniques developed in FY00 for processing 2-frequency GPS data, using an adaptation of the Levenberg-Marquardt algorithm for multiparameter model fits to data. This was necessary in order to improve the accuracy of EDP determination from GPS data. A side benefit is that differential hardware biases are determined more reliably, although this was not reported in detail here.

We have further developed an infrastructure at Geoloc for distribution of ionospheric specification over the Internet in near-real-time.

We have developed a method for combining GPS and UV airglow data for ionospheric specification in a region and formed a preliminary assessment of the validity of present techniques for processing.

We have identified some requirements for future work, in order to reach the above long-term goals.

## RESULTS

We have shown that 2-frequency GPS data can be processed to yield what appears to be reasonably accurate EDPs throughout a region. This is a nontraditional use of these systems. More work is needed for verification of this, including the use of ground-truth incoherent scatter radar data for EDPs. We have investigated the validity of UV airglow data processing for EDP determination and it appears that more work is needed to improve accuracy of these EDPs. Again, more data analysis of the type done here will further clarify the situation. Once the accuracy has been refined, it appears that the combination of GPS and UV airglow data processing will result in the capability of reliable global ionospheric specification (EDPs) and Internet distribution in near-real-time.

## IMPACT/APPLICATIONS

Global ionospheric specification available in near-real-time would be a boon to the development of high-performance satellite radio systems, used for surveillance and intelligence gathering applications, including accurate location of transmitters, military equipment, and buried objects. For example, the cost savings and political consequences of improved targeting would be enormous (smaller bombs and missiles, fewer civilian casualties). The ionospheric specification would also essentially feed on itself, resulting in the development of improved ionospheric models and, thereby, improved ionospheric specification in conjunction with remote sensing data systems.

## TRANSITIONS

RIBG and ITRAY are presently model candidates for ionospheric compensation in DoD radio systems for geolocation and surveillance. A data-driven ITRAY model would enhance its usefulness for this purpose and would probably advance it to the forefront of ionospheric and tropospheric compensation models in satellite radio systems. Geoloc is placing itself in a position to expedite this.

## RELATED PROJECTS

Related projects are: USAF development of a data-driven PRISM model compensation, university development of an assimilating theoretical ionospheric model, and investigations of data fusion for ionospheric specification, centering on Ionosphere World Days (ONR). In addition, there are various institutions working on ionospheric specification from satellite GPS receivers collecting data from limb scans on rising and setting GPS satellite beacons.

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