

GPSProp

**Vertical Electron Density Profile
Calculator**

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Introduction

The ionosphere makes HF propagation possible, whether it's the E layer at about 100 km or the F2 layer at about 300 km. And the height and electron density matter, because, with too little density, our radio signals aren't refracted, they just pass through and exit the ionosphere.

So how do we know whether our signal will be refracted from the ionosphere back to the receiving station? The ionosphere is monitored in several ways. For example, MIT's Millstone Hill radar provides a new vertical electron density profile every 15 minutes. See Figure 1.

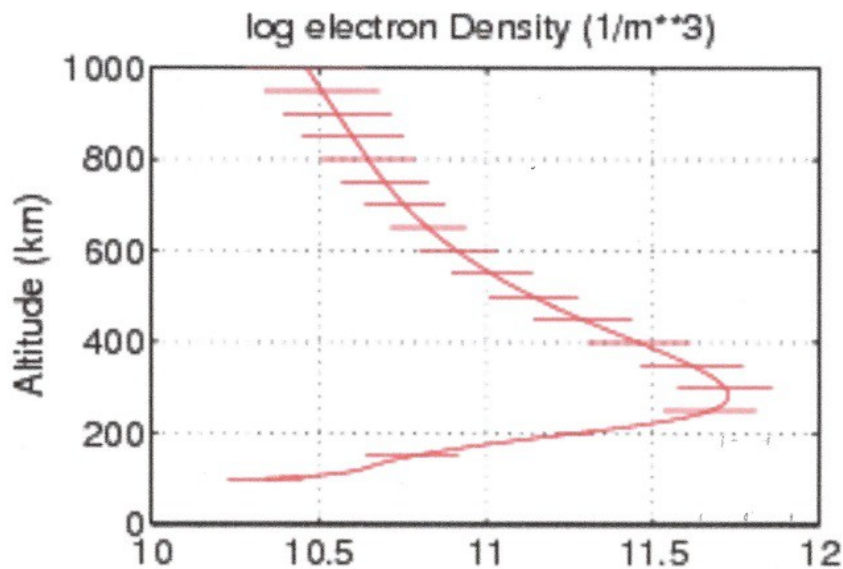


Figure 1: Vertical electron density profile for 3/9/22 at 1647 local time (EST)

Note the pronounced bulge at the F2 layer at about 300 km, and just a hint of an E layer at just over 100 km.

Another method for measuring electron density N_e in the ionosphere makes use of the phase delay produced when GPS signals pass through the ionosphere on their way to ground receivers. The U.S. Space Weather Prediction Center (SWPC) publishes tables in ASCII format that can be used to obtain a vertical electron density profile for a specified latitude, longitude, and altitude. The tables are very large, so manually calculating the density at a given 3-D location is quite tedious. See Figure 2 for calculated

electron densities for various altitudes above Millstone Hill.

```
DOSBox 0.74-3, Cpu speed: 3000 cycles, Frameskip 0, Program: QB
For latitude =          43          degrees
For longitude =        -72          degrees

Height      Electron Density
(Km)        (x 10^11 electrons/m^3)

79          6.295971E-04
104         .1577976
129         .1184291
154         .1702645
179         .3471091
204         .6771016
229         1.03544
254         1.323392
279         1.487149
304         1.528526
329         1.468681
354         1.336124
379         1.162772
404         .9785164

Press any key to proceed.
```

Figure 2: Vertical electron density profile for 3/9/22 at 1630-1645 local time (EST), printed out from the GPSProp app

The Figure 2 data is from GPSProp, an app that reads the SWPC tables and calculates the electron density N_e at a latitude and longitude specified by the user, over the range of specified altitudes. The app is written in QBasic, a DOS-based interpreter.

The curious reader might want to compare the Figure 1 and Figure 2 data. While both show a hint of a bulge at about 104 km (the E layer) and a larger bulge at about 304 km (the F2 layer), the calculated N_e values are not in good agreement. One of the references cited ("Medium-scale 4-D ionospheric tomography..." by M. M. J. L. van de Kamp) compares radar-derived electron density vs. GPS-derived density values, and describes how errors occur.

This document will describe how to use GPSProp, with references provided giving some background on how data similar to the SWPC tables are derived.

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VERTICAL ELECTRON DENSITY PROFILE CALCULATOR

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This software runs with the QBasic interpreter. The GPSProp.bas file and QBasic should be located in the same folder. The software does not include error trapping, so use care when entering data.

This software uses EOF and COE USTEC .txt files from:

<https://services.swpc.noaa.gov/text/us-tec-eof.txt>
<https://services.swpc.noaa.gov/text/us-tec-coefficients.txt>

Create .txt files for the EOF and COE data, after each link is opened, by:

Right-click "Select all"
 Right-click "Copy"
 Open Notepad
 "Paste" onto Notepad
 "Save as" EOF.txt or COE.txt to the Documents folder.
 Copy and paste from the Documents folder to the C:\Test\QBasic\qb45\QB45 folder. See the GPSProp Instructions for opening the GPSProp app with vDosPlus and QBasic.

Enter Latitude, Longitude and Altitude, using input codes from the chart below.

Example: For 38.5° latitude, -108° longitude and 1004 km altitude, enter 5,14,38 (separate input codes with commas).

For a scan of all altitudes, enter a zero for the altitude code.

Example: For all altitudes above 38.5° latitude and -108° longitude, enter 5,14,0

Code	Lat.*	Long.	Alt.	Code	Lat.	Long.	Alt.
-----	-----	-----	-----	-----	-----	-----	-----
1	32.5	-160.0	79	22	----	-76.0*	604
2	34.0	-156.0	104	23	----	-72.0	629
3	35.5	-152.0	129	24	----	-68.0	654
4	37.0	-148.0	154	25	----	-64.0	679
5	38.5	-144.0	179	26	----	-60.0	704
6	40.0	-140.0	204	27	----	-56.0	729
7	41.5	-136.0	229	28	----	-52.0	754
8	43.0	-132.0	254	29	----	-48.0	779
9	44.5	-128.0	279	30	----	-44.0	804
10	----	-124.0	304	31	----	-40.0	829
11	----	-120.0*	329	32	----	----	854
12	----	-116.0*	354	33	----	----	879
13	----	-112.0*	379	34	----	----	904
14	----	-108.0*	404	35	----	----	929
15	----	-104.0*	429	36	----	----	954
16	----	-100.0*	454	37	----	----	979
17	----	-96.0*	479	38	----	----	1004
18	----	-92.0*	504	39	----	----	1029
19	----	-88.0*	529	40	----	----	1054
20	----	-84.0*	554	41	----	----	1079
21	----	-80.0*	579	42	----	----	1104

Table continued next page

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Code	Lat.	Long.	Alt.	Code	Lat.	Long.	Alt.
43	----	----	1129	49	----	----	1279
44	----	----	1154	50	----	----	1304
45	----	----	1179	51	----	----	1329
46	----	----	1204	52	----	----	1354
47	----	----	1229	53	----	----	1379
48	----	----	1254	54	----	----	1404

All latitude values are within Continental U.S. (CONUS). All longitude values with asterisks (*) are within CONUS. Use longitude values within CONUS for best accuracy.

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GPSPROP INSTRUCTIONS
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- 1 Download GPSProp from <https://www.qsl.net/wa6nut>
Download QBasic 4.5 from <https://www.qbasic.net/>
Download vDosPlus from <http://vdosplus.org>
- 2 Locate GPSProp in the C:\Test\QBasic\qb45\QB45 folder with QBasic and associated files in the same folder, including the EOF.txt and COE.txt files.
- 3 vDosPlus will be located in the C:\vDosPlus folder. Open the config file in that folder and edit as follows:

Edit (under "Mouse"):
from: rem MOUSE = ON to: MOUSE = ON

Print to printer option:
Add (under "Printing"):
LPT1 = /SEL2 /CPI8 /F'Arial' /LAND /LEFT1.00 /TOP1.00

OR

Print to PDF option:
Add (under "Printing"):
LPT1 = /SEL2 /CPI8 /F'Arial' /LAND /LEFT1.00 /TOP1.00 /PDP

- 4 Open vDosPlus.
- 5 After the C:\> prompt, type "USE c: c:\Test\QBasic\qb45\QB45" vDosPlus responds with "C=> c:\Test\QBasic\qb45\QB45\" and the C:\> prompt.
- 6 After C:\> prompt, type "QB.exe"

- 7 This opens QBasic. Press the Esc key, then click "File" then click "Open Program"
- 8 Click on "GPSPROP.BAS" then "OK" You'll see the listing of the GPSProp BASIC code displayed. Press the Shift+F5 keys to open GPSProp.
- 9 The the GPSProp opening screen will be displayed. Follow the prompts in GPSProp to obtain the electron density data you want.

10 Print to printer option (Step 3):

Type Y at the "Type Y for printout (vDosPlus), N for no printout" prompt.

The vDosPlus app will respond with the "Select Destination dialog" prompt. Click on "Print" and your printer will print the GPSProp data shown on the screen.

Print to PDF option (Step 3):

Type Y at the "Type Y for printout (vDosPlus), N for no printout" prompt.

The vDosPlus app will respond with the "Select Destination dialog" prompt. Click on "Preview" and the GPSProp data shown on the screen will be loaded as a PDF file into the C:\vDosPlus folder. Note that four files total are loaded to the C:\vDosPlus folder for each print-to-PDF operation:

```
#LPT1 (a .asc ASCII file)
#LPT1.asc (your PDF file)
#LPT1.asc_1 (an EMP file suitable for editing in Paint)
and #LPT1 (a .txt file)
```

Note that these four files overwrite any .asc, PDF, EMP and .txt files loaded by a previous print-to-PDF operation, so any of these files needed must be relocated to another folder before performing another print-to-PDF operation.

- 11 After quitting the GPSProp program, you'll return to the same QBasic screen as in Step 8. Click on "File" then on "Exit" Click on "No" if the "One or more loaded files are not saved. Save them now?" prompt is displayed. This will return you to the vDosPlus screen.
- 12 At the C:\> prompt, type "exit" to exit vDosPlus and return to Windows.

Verify Operation of GPSProp

- 1 Download EOF and COE files from swpc.noaa sites and save as EOF.txt and COE.txt in the C:\Test\QBasic\qb45\QB45 folder.
- 2 Run GPSProp at latitude = 43.0° and longitude = -72° (enter as 8,23,0) and obtain screen prints.
- 3 Convert electron density N_e to $\log_{10}(N_e)$ at various altitudes, where N_e = electron density (given in units of 10^{11} electrons/m³). Note that $\log_{10}(N_e)$ values will typically be between 11.0 and 11.9)
- 4 Obtain electron density (\log_{10}) vs. altitude plot calculated from Millstone Hill Radar Models at:

<http://models.haystack.mit.edu/models/>

Click on "Realtime"

Note that Millstone Hill is at latitude = 42.62° and longitude = -71.49°

- 5 Compare GPSProp electron densities (\log_{10}) from Step 3 with the electron densities (\log_{10}) on the Millstone Hill Radar plot at the various altitudes in Step 3.
- 6 You can also compare the GPSProp electron densities with critical frequencies on the Millstone Hill ionogram plot at:
<https://lgdc.uml.edu/common/DIDBYearListForStation?ursiCode=MHJ45>
Click below:
<https://lgdc.uml.edu/common/DIDBYearListForStation?ursiCode=MHJ45>

Notes

- 1 The COE file is organized into 3 sets of N ($= 47$) latitude rows, with N_s ($= 1.5^\circ$) spacing, starting at N_0 ($= 1^\circ$) ($3 \times N = 141$ rows total). Each set corresponds to a column in the EOF file. The COE file has M ($= 31$) longitude columns, with M_s ($= 4^\circ$) spacing, starting at M_0 ($= -160^\circ$).

The EOF file is organized into N_a ($= 52$) altitude rows, with D_h ($= 25$ km) spacing, starting at h ($= 6446.34$ km) from the center of the earth. The EOF file has N_e ($= 3$) columns. Each element in an EOF file row corresponds to an element in a corresponding set in the COE file.

So the calculated electron density (in electrons/ $m^3 \times 10^{11}$) is the sum of 3 products, with each product composed of an altitude value from an EOF column and a latitude, longitude value from the corresponding set in the COE file.

See the paragraphs titled "Daily Empirical Ortho-Normal Functions (EOFs)," "Coefficients," "Using Daily Empirical Ortho-Normal Functions (EOFs) and Coefficients," and "Electron Density" at the following link:

<https://www.ngdc.noaa.gov/stp/iono/ustec/README.html>

- 2 The theory (simplified) behind GPS-derived electron density profiles is found at the following link:
<https://space.fmi.fi/MIRACLE/Geotrim/Theory.html>

More details, including a discussion of accuracy, are found at the following link:

https://www.researchgate.net/publication/279412186_Medium-scale_4-D_ionospheric_tomography_using_a_dense_GPS_network

Click below:

https://www.researchgate.net/publication/279412186_Medium-scale_4-D_ionospheric_tomography_using_a_dense_GPS_network

More Resources

Here are a couple of YouTube presentations on ionospheric tomography. The speaker, Gary Bust, presents an interesting overview without unnecessary math or scientific jargon. The first presentation is here:

Ionospheric Imaging: From two-dimensional tomography to data assimilation

https://www.youtube.com/watch?v=fWbhPX0b9d0&t=1466s&ab_channel=CEDARScience

Click on:

https://www.youtube.com/watch?v=fWbhPX0b9d0&t=1466s&ab_channel=CEDARScience
(fast forward and watch the segment at 13:30-20:30 min)

This presentation explains how tomography works (note that tomography is also used in CAT scans, as he demonstrates, showing a cat near a CAT scan machine).

Here is another presentation, also by Dr. Bust:

Ionospheric Imaging and Data Assimilation

https://www.youtube.com/watch?v=Gzrad16gN8k&t=338s&ab_channel=CEDARScience

Click on:

https://www.youtube.com/watch?v=Gzrad16gN8k&t=338s&ab_channel=CEDARScience
(fast forward and watch the segment at 5:13-20:10 min)

This presentation gives a simple explanation of how inverse theory works. Dr. Bust explains it using the behavior of teenagers and Sherlock Holmes.

Also see **Ionosphere: Tutorial** at:

http://gnss.be/ionosphere_tutorial.php#x2-70000

Scroll down to "How to Obtain a 4-D Image of the Electron Concentration of the Ionosphere?"

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