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Aerospace Radio Frequency Propagation Tool (ARPT) User Guide

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Abstract

The Aerospace Radio Frequency (RF) Propagation Tool User Guide provides instructions on the use of the Aerospace RF Propagation Tool (ARPT). The tool uses the Split Step Parabolic Equation method to calculate RF propagation loss for any specific site over long path lengths. It can incorporate United States Geological Survey (USGS) terrain data, National Oceanic and Atmospheric Administration (NOAA) weather data, and measured transmit antenna radiation patterns. Model results have been verified with RF measurements for path lengths from 6 to 120 km, across various terrain profiles, and under near real-time weather conditions. Through this user guide, users can learn how to properly configure and operate the tool.

Acknowledgement

The Aerospace Corporation would like to acknowledge and thank Dr. Ozlem Ozgun for allowing Aerospace to reuse parts of the SSPE algorithm in order to develop this propagation tool.

Contents

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1. System and Software Requirements

1.1 Operating System (OS) Requirement

It is recommended to use Windows 7 64-bit OS. The tool was developed and tested under Windows 7 Pro 64-bit OS.

1.2 Central Processing Unit (CPU) Requirement

It is recommended to have a central processing unit with a high clock speed. The tool was developed and tested using Intel Xeon E5-1650 version 3 with CPU clock speed of 3.50 GHz.

1.3 Memory Requirement

It is required to have a minimum of 16 GB of memory and recommended to have 32 GB of memory. The tool was developed and tested using 16 GB of memory.

1.4 Storage Requirement

It is recommended to use a solid state drive. However, the tool will work on any modern hard drives. The tool was developed and tested on both hard and solid state drives.

1.5 Runtime Library Requirement

The tool was developed using Matlab version R2015B. To run the ARPT, MATLAB Runtime for Matlab version 9.0 must be installed.

1.6 Screen Resolution Requirement

The tool was developed under screen resolution of 1920 by 1200 (1200p) to prevent crowding of buttons and plots. It is required to run the tool in a computer that is capable of supporting resolution of 1920 by 1200 (1200p) or higher.

2. Aerospace RF Propagation Tool at a Glance

The ARPT is a tool that predicts the path loss between two locations. It uses the Fourier Split Step (FSS) algorithm to solve the parabolic wave equation also referred to as Split Step Parabolic Equation (SSPE) that is derived from the scalar version of Helmholtz equation. There is abundant literature related to this topic; for references please refer to section 6.

Major advantages of this tool compared to other propagation tools are that it is able to utilize custom antenna patterns, site specific weather and terrain profiles, and determine path loss as a function of height and range.

3. Getting Started

Inputs can be sub-divided into five sections: SSPE parameters, transmitter source information, terrain profile, weather profile, and receiver parameters. Understanding and providing correct inputs to the model are essential to utilizing the ARPT to produce meaningful results.

3.1 Transmitter Source Information

Detailed transmitter inputs allow the model to completely characterize the transmitter source such as capturing the side lobes of the antenna in addition to the main lobe. The transmitter inputs are: frequency of the signal of interest, 3dB beam width, antenna pattern, antenna tilt angle, and transmitter height.

3.1.1 Implementation of Custom Antenna Pattern

Using Gaussian as the antenna pattern for any location can be misleading since the main beam might not be received by the receiver antenna due to restrictions such as Transmit Inhibit Zone (TIZ). For these circumstances, implementing a custom antenna pattern is critical to produce results that are closer to the actual RF measurements. Readers interested can refer to the following article, "UHF Propagation Prediction in Smooth Homogenous Earth Using Split-step Fourier Algorithm" [4].

3.2 Terrain Data

The terrain data used for the propagation model was obtained from United States Geological Survey (USGS) and is called Digital Terrain Elevation Data (DTED) that mainly characterizes diffraction in Electromagnetic (EM) effects. There are two sets of DTED available: DTED-1 which provides terrain data with 3 arc-seconds of resolution (100 meters) in grid format and DTED-2 with a resolution of 1 arc-seconds (30 meters) in grid format. Only the terrain data between transmitter and receiver is needed hence the extracted data is a 2-Dimensional (2-D) data.

The data format requirements for terrain profile is the following:

1. File extension must be in .txt.
2. Column 1: Distance from transmitter in any step sizes where units are in km.
3. Column 2: Height above mean sea level where units are in meters for each values of column 1.

For Example: terrain_data1.txt

```
5.14    2.88
7.32    10.58
9.50    18.27
11.14   33.65
12.95   41.35
15.23   50.96
16.95   60.58
19.41   74.04
21.41   97.12
23.68   106.73
```

3.3 SSPE Parameters

The maximum height parameter will set the highest altitude point where the field and path losses will be calculated. It is critical that maximum height does not over extend above the weather data. In addition, user should be aware that the higher the maximum height is set to the more calculation time the tool will require. Optimal maximum height input was between 2000 to 2500 meters.

3.4 Weather Data

Weather plays a key role in determining index of refraction. The weather data used for the propagation model was obtained from the National Oceanic and Atmospheric Administration (NOAA). The High Resolution Rapid Refresh (HRRR), as the weather data is called, is a real-time 3 km grid spacing that provides forecast every 15 minute intervals, issued once every hour. Weather data used for ARPT was downloaded from NOAA then extracted only up to 4km in height.

ARPT primarily uses index of refraction data extracted from HRRR in predicting path loss. Hence after index of refraction data is extracted from HRRR, weather data must be formatted correctly to be utilized with the tool. The format for creating custom weather input data was reused with permission granted from Dr. Ozlem Ozgun [3].

The data format for weather profile after it has been extracted from HRRR and converted to index of refraction is the following:

1. File extension must be in *.mat
2. Four parameters must be filled in the following manner:
   a. Duct Height Array (duct_height_array2 in Matlab) where units are in meters
   b. Duct Modified Index Array (duct_M_array2 in Matlab) where units are in modified index of refraction. If index of refraction is known, it can be converted to Modified Index of Refraction through the following equation [1]:

$$M = \left(n^2 - 1 + \frac{2z}{a_e}\right) \times 10^6 \tag{3-1}$$

where z is the height above surface in meters and a_e is the Earth's radius in meters.

3. Distance from Transmitter (duct_range_array in Matlab) where units are in km
4. Duct Type Array (duct_type_array2 in Matlab)

All of these parameters must be filled correctly to create a user defined weather profile that can be used with the tool.

- Duct Height Array, each row provides the height of values where the modified index can be set or changed.
- Duct Modified Index Array, each row corresponds to the modified index value at the defined heights which were defined in Duct Height Array.
- Duct Range Array, each value in row corresponds to when the vertical weather profile will change. For example, if entries were 0 and 2 this means that first vertical weather profile is used from 0 km to 2 km and 2nd vertical profile is used from 2km onward. It is critical that the end value of this array entry matches with the terrain profile as shown in example below.
- Duct Type Array will be populated with value 6 which represents user-defined array. The size of Duct Type Array and Duct Range Array should have the same number of elements while Duct Height Array and Duct Modified Index Array should have same number of elements.

For example: atm1.mat

duct_type_array2 = $[6 \quad 6 \quad 6 \quad 6]$

duct_range_array = $[0 \quad 5 \quad 15 \quad 23.68]$

duct_height_array2 = $\begin{bmatrix} 0 & 200 & 0 & 0 \\ 0 & 10 & 20 & 75 \\ 0 & 50 & 150 & 200 \\ 0 & 100 & 300 & 0 \end{bmatrix}$

duct_M_array2 = $\begin{bmatrix} 300 & 320 & 0 & 0 \\ 300 & 310 & 290 & 400 \\ 310 & 300 & 340 & 320 \\ 300 & 290 & 340 & 0 \end{bmatrix}$

3.5 Receiver Information

The receiver information consists of the height at which the receiver antenna is placed above sea level. Receiver height should be known to determine the propagation loss approximately at receiver height. Resolution of height is dependent on wavelength which is dependent on the frequency of interest hence, the tool simulates receiver height more accurately with higher frequency.

4. Basic Operations

Aerospace RF Propagation Loss Tool is simple to operate once all the necessary terrain and weather files are obtained.

1. To run the tool, type in “ARPT” in command window for Matlab as shown in **Error! Reference source not found.**. (Note: Matlab directory should be set to where the program directory lies.)

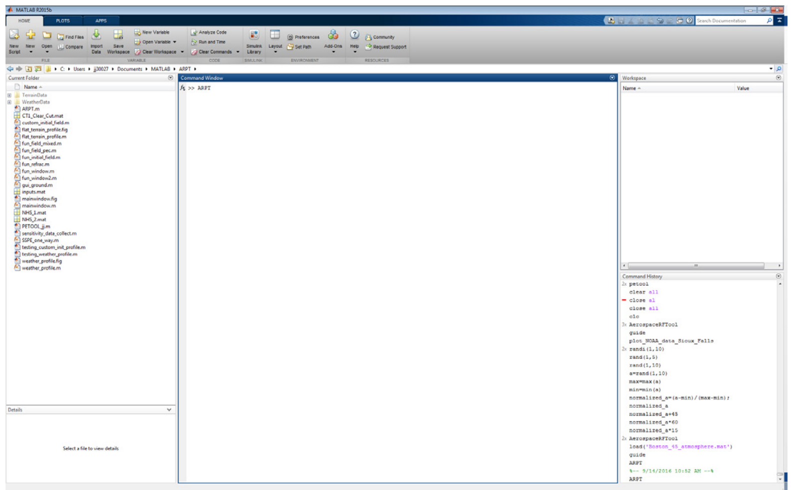

Figure 1. Execute the tool in Command Window.

2. Graphical User Interface (GUI) will pop up in the center of the window as shown in Figure 2.

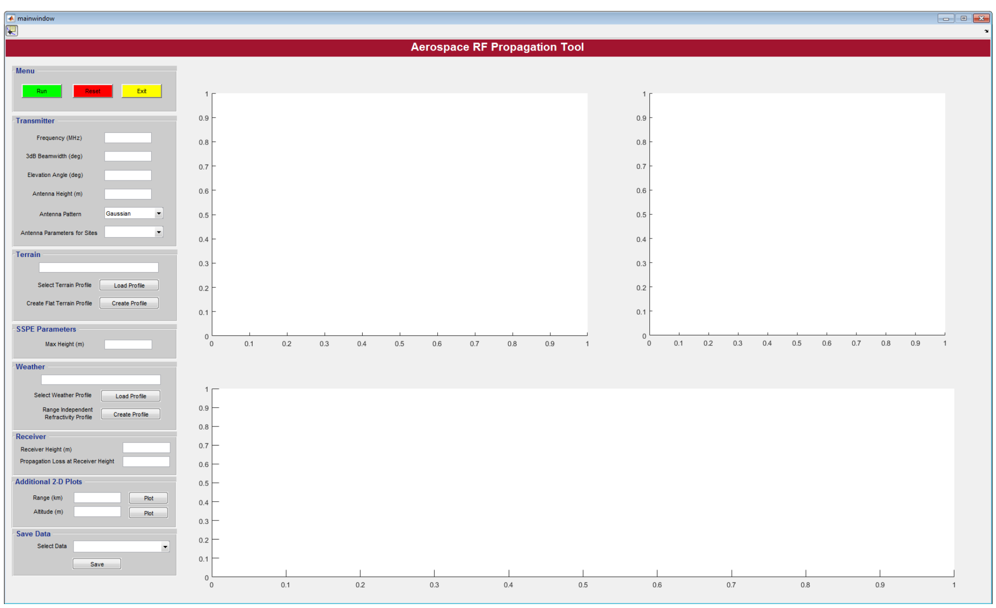

Figure 2. Main GUI.

3. User needs to enter the following parameters before the tool can simulate the propagation loss.
   a. Transmitter Information
      (1) Signal Frequency in MHz
      (2) 3dB Beamwidth in degrees

(3) Elevation angle of antenna in degrees
(4) Transmitter antenna height above mean sea level
(5) Antenna pattern needs to be selected where default is Gaussian field
(6) User can also select predefined Antenna Pattern for Sites where transmitter information and receiver height information are predefined except for the antenna pattern

b. Terrain Information
   (1) Terrain file should be selected by clicking the Load Profile button. A new window will allow the user to select the desired terrain profile. (Note: When the terrain file is selected, the terrain profile will be plotted in the bottom half of the GUI.)

c. SSPE Parameters
   (1) Max Height needs to be entered by the user and it should be greater than or equal to 1800 meters. (Note: User should be aware that even though there is no limit for max height, for computation speed and performance, the max height parameter should be kept between 1800 to 3500 meters.)

d. Weather Information
   (1) Weather file should be selected by clicking the Load Profile button and it will show another window where user can select the desired weather profile.

e. Receiver Information
   (1) Receiver height above mean sea level in meters should be entered.

4. When all the information is entered, GUI will look similar to Figure 3.

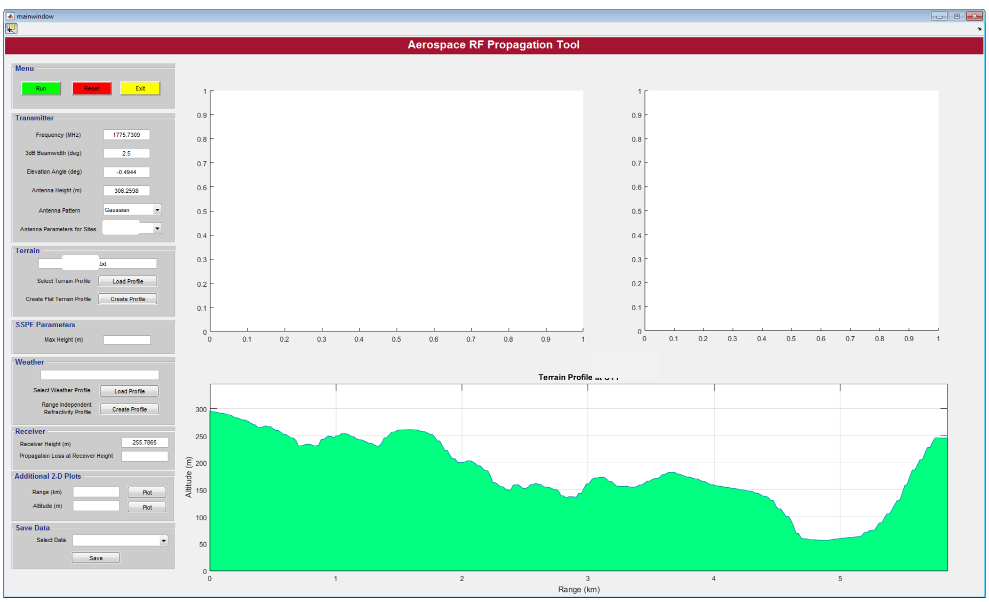

Figure 3. Terrain profile loaded.

5. Press the green "Run" button in the Menu section shown in Figure 4 to calculate the propagation loss. As soon as the user clicks the run button a status window with "Please Wait" will pop up while the tool is performing calculations as shown in Figure 5. User will need to wait for the status box to disappear. Wait time can be anywhere from 10 seconds to 15 minutes depending on terrain profiles and max height.

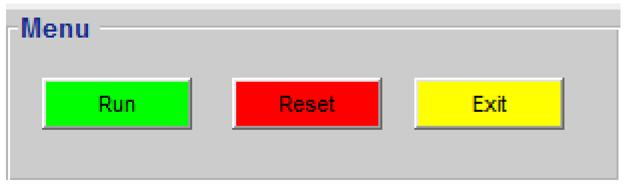

Figure 4. Menu section.

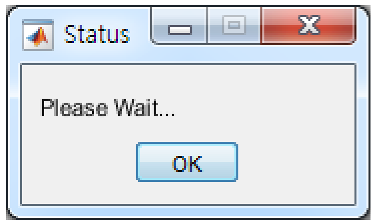

Figure 5. Wait box.

6. After the message box disappears, the GUI will be automatically updated and will now appear similar to Figure 6.

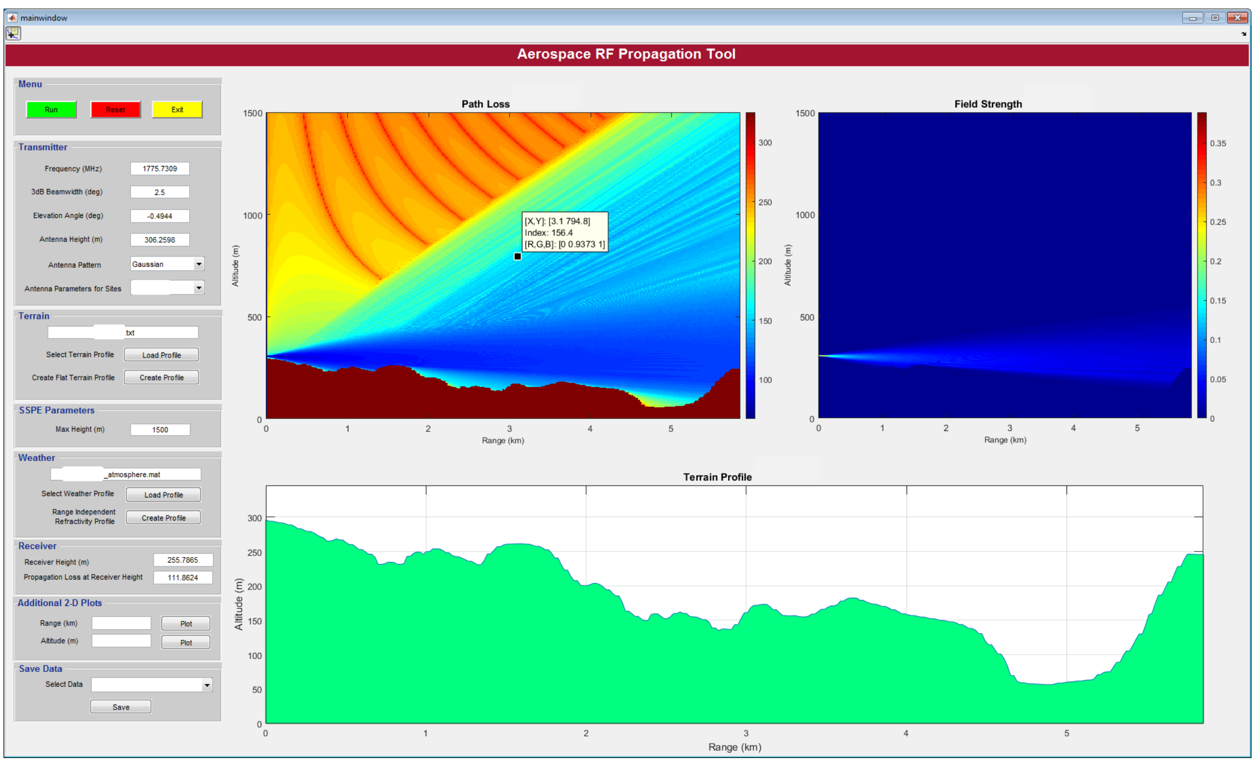

Figure 6. Path loss calculation completed.

7. User can see the values in the images by left clicking on all of the plots shown in Figure 6.

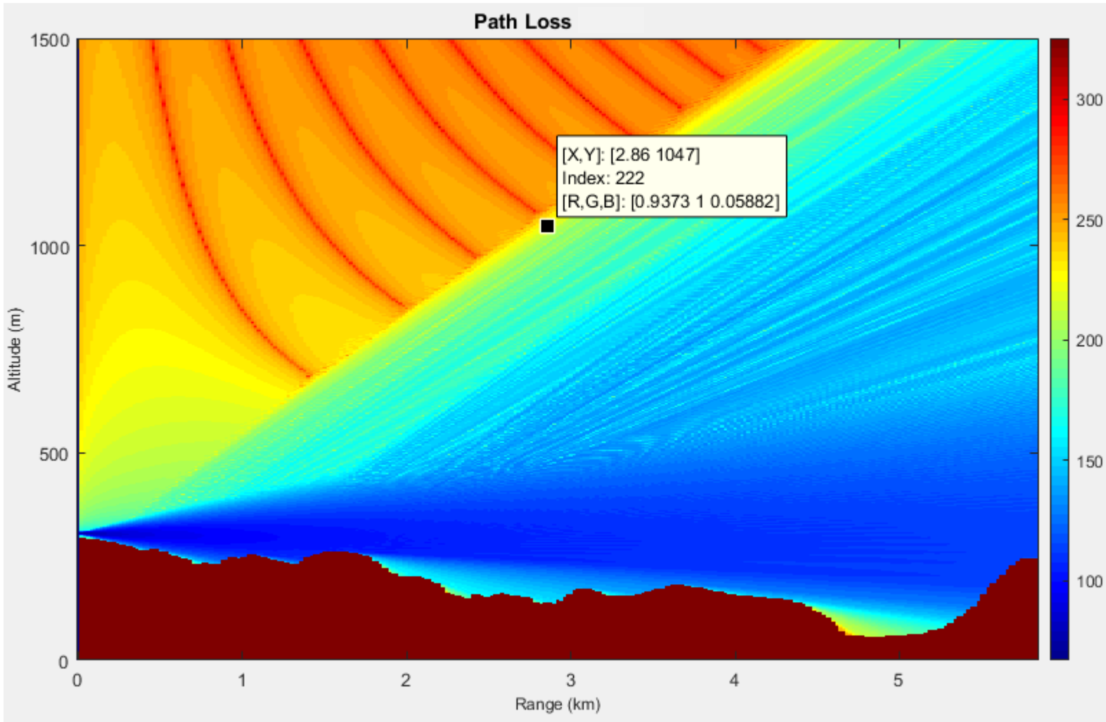

Figure 7. Path loss plot.

For example, as shown in Figure 7 by left clicking on the plot itself, information for that particular point will be displayed. Index means path loss in dB hence for Figure *7* the black tool tip shows the user that at that particular point, path loss is 222 dB at 2.86 km in range with 1047 meters height above mean sea level.

8. To create multiple data cursor information boxes, user can go to a different plot then right click and select "Create New Data Tip" from the pop-up menu. This can be useful for quick visual inspection as shown in Figure *8*. There is no limit to how many new data tips can be placed on each of the plots. To remove all or current data tips user can right click to bring up the pop-up menu and select delete all data tips or delete current data tip.

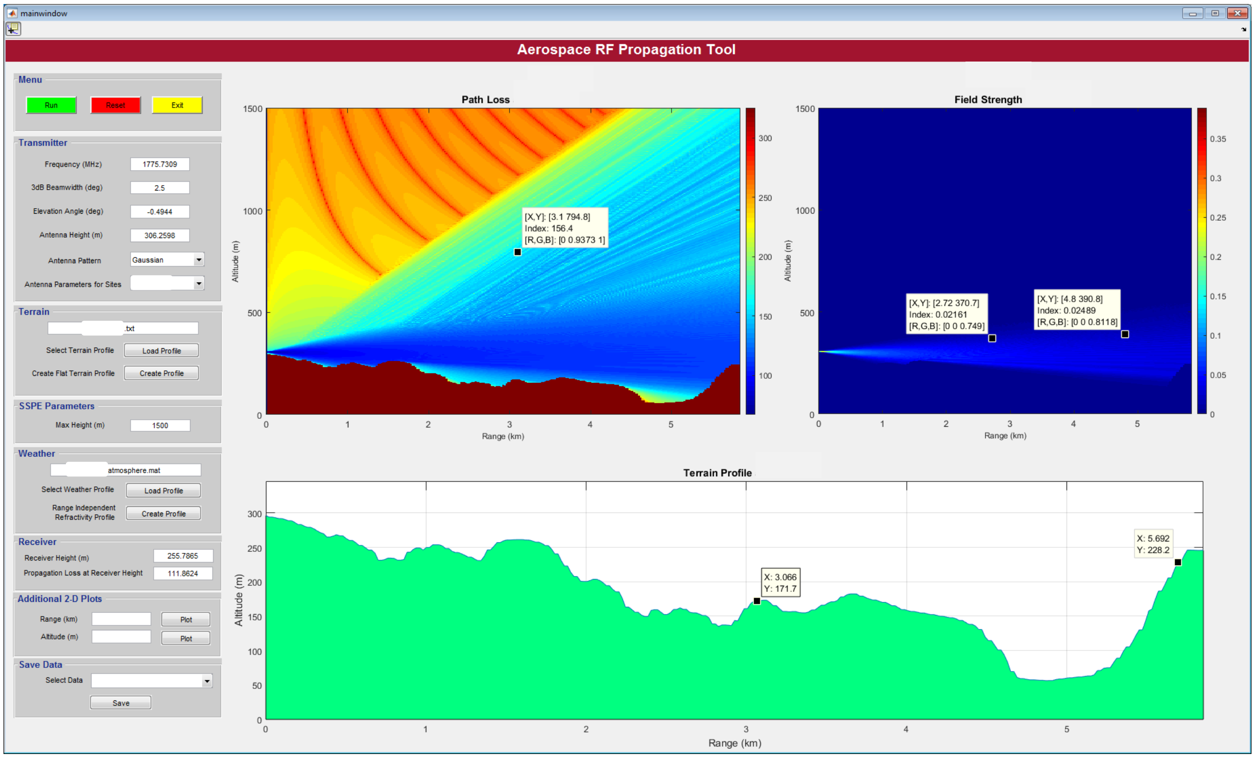

Figure 8. Multiple Data Tips.

9. Creating many data tips to view each data can become a problem hence if user wants to know the path loss results for a certain altitude at all ranges or path loss at a certain range for all heights up to max height then user can utilize the “Additional 2-D Plots” section in the menu.
   a. User can enter an altitude value and after entering the value, click the plot button to the right of the input box to see the plot similar to shown in Figure 9. The plot will show two curves: one representing the free space loss and the other the propagation loss or path loss.

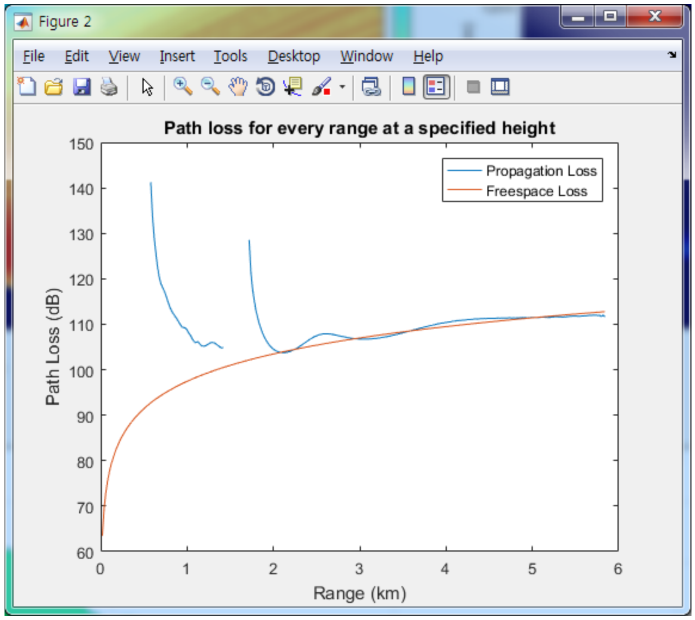

Figure 9. Path loss for every range at a specified height.

b. User can enter an specific range value and after entering the value click the plot button to the right of the input box to see the plot similar to shown in Figure 9. Range value is limited by the actual terrain profile used hence it is recommended that user knows exactly what the last range value is for the terrain file that is being simulated.

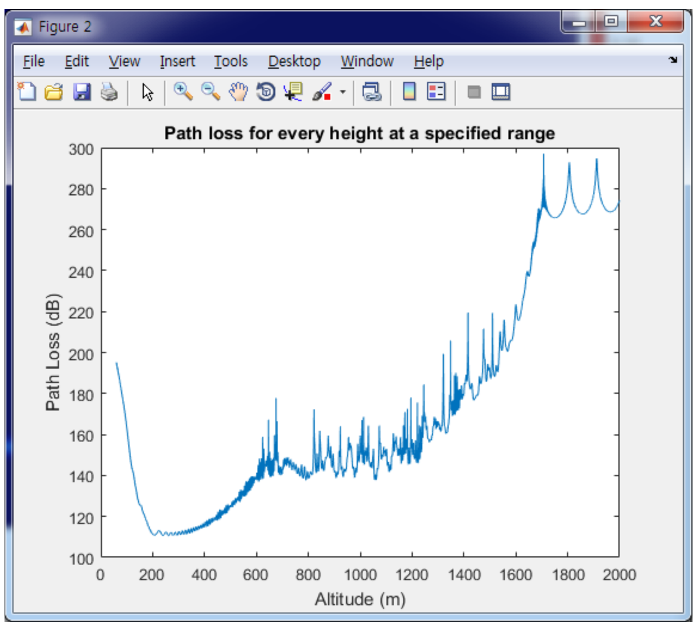

Figure 10. Path loss for every height at a specified range.

Data tip can be placed for both Figure *9* and Figure 10 by clicking on the data cursor which is shown in Figure 11.

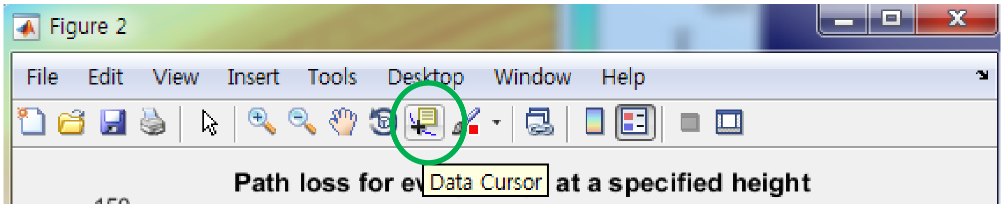

Figure 11. Data cursor.

Before new scenarios are ran, user should close extra figures that are opened by utilizing "Additional 2-D Plots" to avoid confusion when new plots are created for a new scenario.

10. To save the actual values instead of plots, the last menu that is placed at the bottom, "Save Data" can be utilized. User can select a specific data and after selecting from various options click "Save" button to save the data. The data will be saved in the same directory where the tool's m-files are located.
11. To clear all the input parameters except terrain and weather profiles, user can click the "Reset" button colored in red on the menu section.
12. To exit the GUI, user can click the "Exit" button colored in yellow on the Menu section.
13. To save the path loss data in Comma Separated Value (CSV) format, user can use the Save Data section of the GUI as shown in Figure 12 to save the path loss as a function of height and range for a particular simulation.

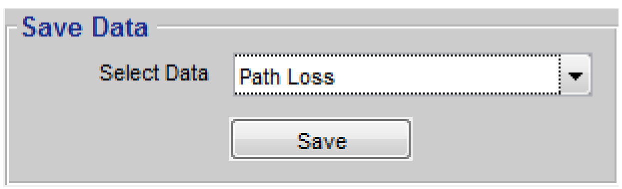

Figure 12. Save path loss data.

5. Other Operations

Previous section showed how to operate the tool with an underlying assumption that weather and terrain profile was already created ready to be used. This section will investigate two options in the GUI that were not covered: Create Flat Terrain Profile in terrain menu and Range Independent Refractivity Profile in weather menu. In circumstances, where user did not have any terrain and weather profile to load into the tool, a simple flat terrain with range independent refractivity weather profile can be used.

5.1 Create Flat Terrain Profile

When create profile button is clicked another window will pop up as shown in figure. It is important that the user must have filled out all the Transmitter parameters before the create profile button is clicked. Once all the Transmitter parameters are filled in create profile button will pop up another window as shown in Figure 13.

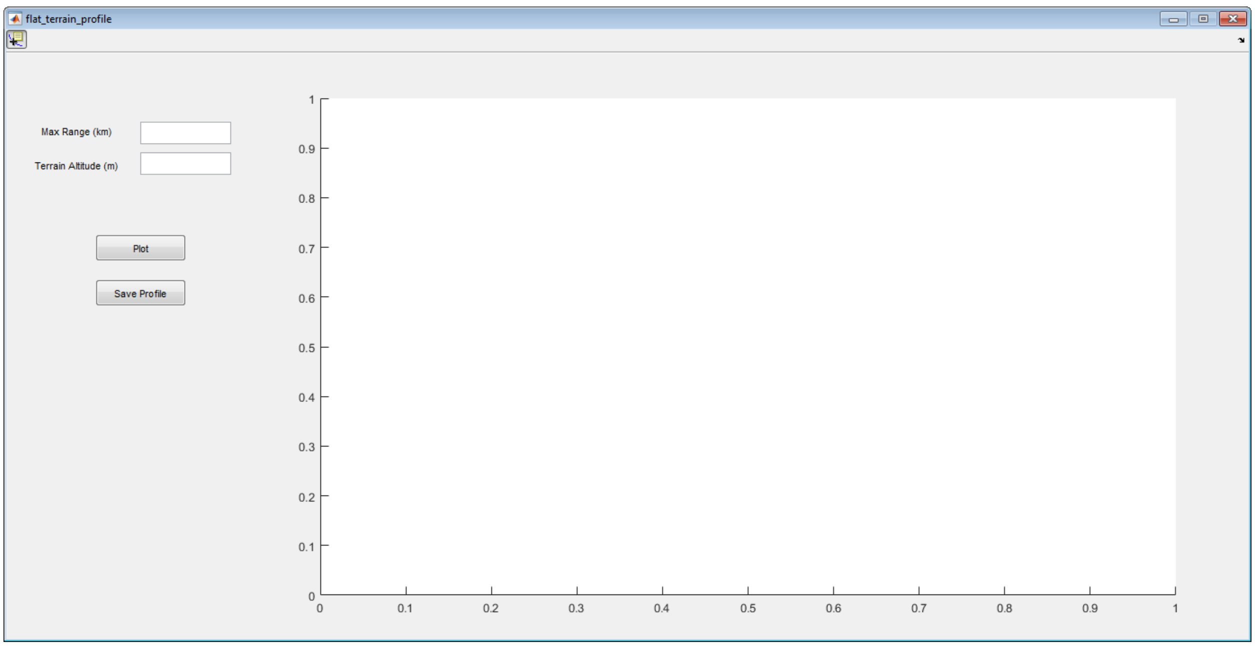

Figure 13. Create flat terrain profile window.

To create a flat terrain, user enters the maximum end range and the flat terrain altitude in meters. User can verify the terrain by pressing the plot button and flat terrain file will be plotted as shown in Figure 14.

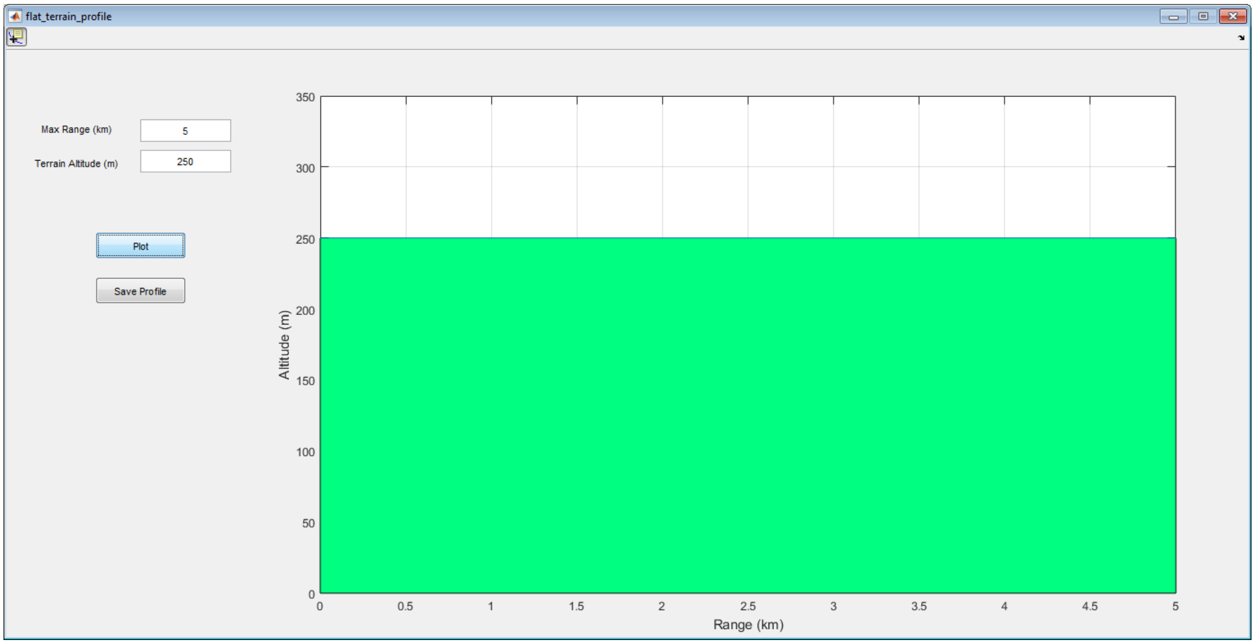

Figure 14. Flat terrain.

After viewing the plot, it can be saved as a profile by clicking the save profile button then by closing the window flat terrain profile can be used as a profile by selecting the file which is named as "flat_terrain.txt".

5.2 Create Range Independent Refractivity Weather Profile

There are various atmosphere types that the user can choose such as standard atmosphere, surface duct, surface based duct, elevated duct, evaporation duct, and user defined. The entries to be filled out will be different depending on the types. It is important to keep in mind that refractivity profiles will be same for the entire range hence refractivity does not change through each step in range. For example, a simple fictitious atmosphere was created as shown in Figure 15 and saved by pressing save profile button. File names will be the atmosphere type that the user has selected. For example, Standard Atmosphere will be saved as "Standard_Atmosphere.mat".

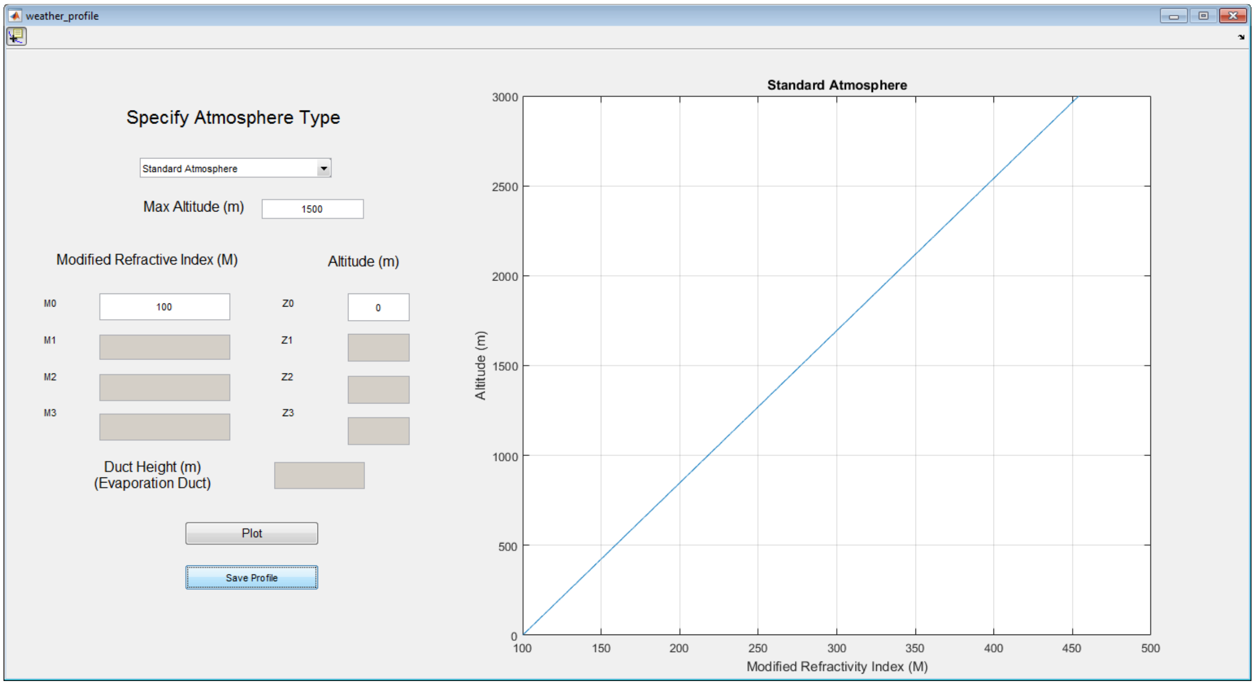

Figure 15. Create range independent refractivity profile.

By loading two profiles "flat_terrain.txt" and "Standard_Atmosphere.mat", Figure 16 is the final outcome.

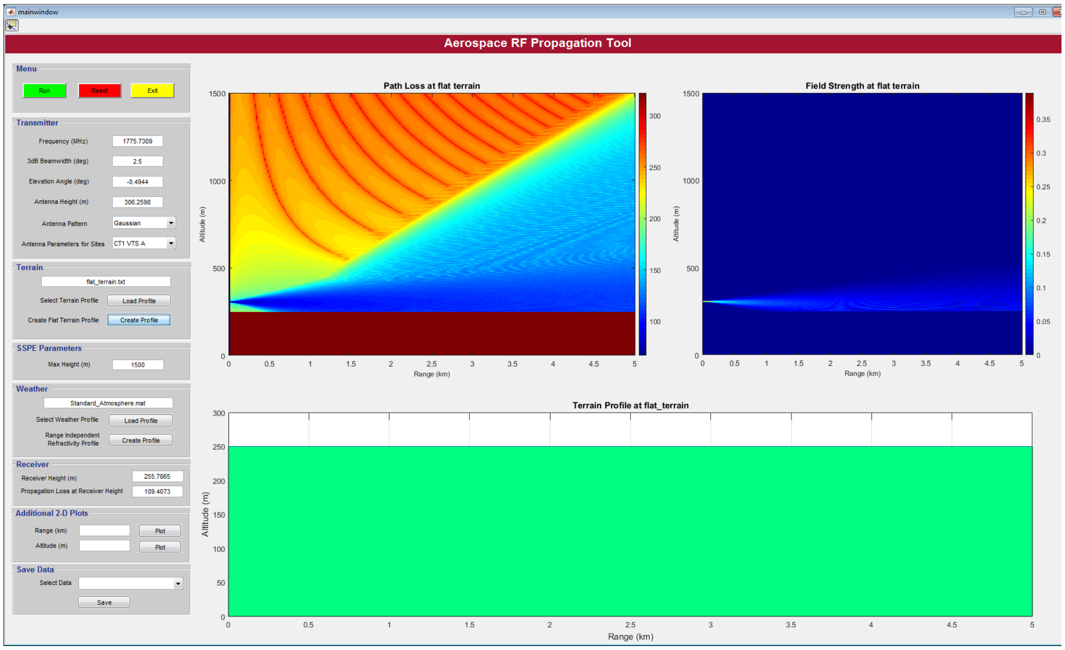

Figure 16. Using flat terrain and range independent weather profile.

6. Disclaimer

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8. Acronyms

2-D	Two-dimensional
ARPT	Aerospace RF Propagation Tool
CPU	Central Processing Unit
DTED	Digital Terrain Elevated Data
GUI	Graphical User Interface
OS	Operating System
FSS	Fourier Split-Step
HRRR	High Resolution Rapid Refresh
NOAA	National Oceanic and Atmospheric Administration
TIZ	Transmit Inhibit Zone

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