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Aerospace Radio Frequency Propagation Tool (ARPT) User Guide 2.0

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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 (SSPE) method to calculate RF path loss for any specific site over long distances. It can incorporate United States Geological Survey (USGS) terrain data, National Oceanic and Atmospheric Administration (NOAA) weather data, and measured transmitter 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.

Revision History

ARPT Revision	Description of Change	Date
Version 1	• Main window layout of ARPT revised • Axis labels revised	1/2/2017
Version 2	• Implementation of Parabolic Taper Antenna Pattern • Implementation of directly using HRRR GRIB file for near real-time weather data • Implementation of loading custom antenna profiles	3/1/2017

Contents

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1. System and Software Requirements

This user guide refers to the ARPT version 2.0.

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 single 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 or higher. 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 drive. The tool was developed and tested on both hard and solid state drives.

1.5 Runtime Library Requirement

The tool was developed and tested using Matlab version R2016B. To run the ARPT, runtime library for Matlab 2016B (version 9.1) must be installed on computers that do not have Matlab 2016B installed.

1.6 Screen Resolution Requirement

The tool was developed under a screen resolution of 1920 by 1200 (1200p) to prevent crowding of buttons and plots. It is required to run the tool on a desktop 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 an 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 will predict a more accurate 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 How to run ARPT

1. To run ARPT, extract the zip file to a folder and double click "ARPT.exe" as shown in Figure 1. (Note: Do not delete any files or folders that were extracted from the zip file.)

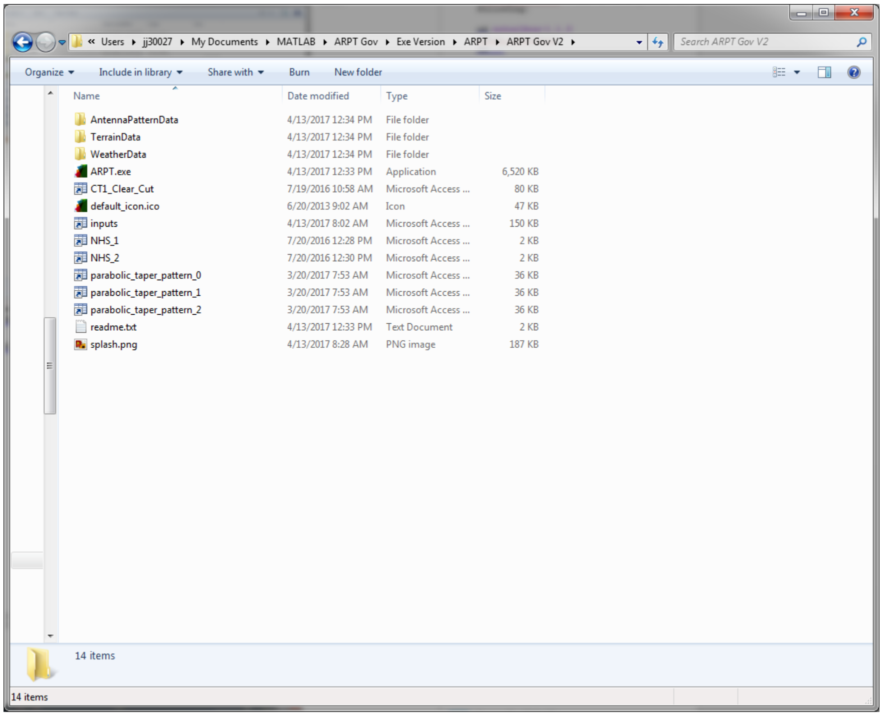

Figure 1. Execute the tool in Command Window

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

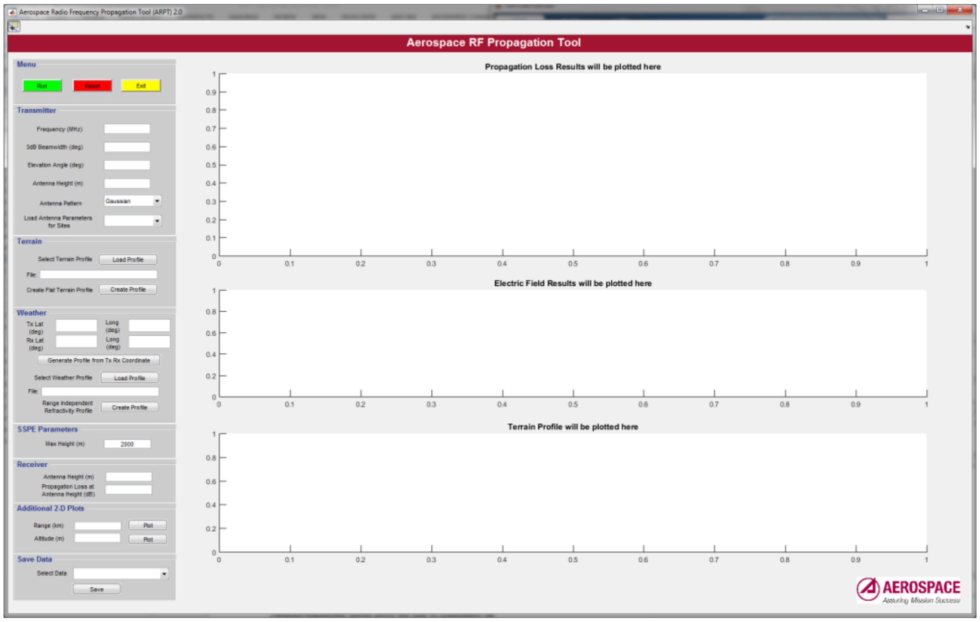

Figure 2. Main Window of ARPT

3.2 Transmitter Source Information

Detailed transmitter inputs allow the user 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 center frequency of the signal of interest in MHz, 3dB beam width in degrees, antenna pattern, antenna tilt angle in degrees, and transmitter height in meters. Transmitter height is the height from above mean sea level to the antenna feed in meters. Different antenna patterns can be selected from the drop-down menu in Transmitter sub-menu. Details of selectable antenna patterns are explained in the following sections.

3.2.1 Gaussian Antenna Pattern

The theoretical Gaussian antenna pattern is the default antenna pattern and it should be used mostly for line of sight cases. For implementation details refer to reference “Electromagnetic Modeling and Simulation” [2]. However, using Gaussian as the antenna pattern for no-line of sight cases can be misleading since the main beam might not be received by the receiver antenna due to Gaussian antenna pattern implementation. For these circumstances, using the parabolic taper antenna pattern or implementing a custom antenna pattern is recommended to generate propagation results that are closer to the actual RF measurements.

3.2.2 Parabolic Taper Antenna Pattern

Gaussian antenna pattern does not have any side lobes and therefore, the user has the option to use parabolic taper antenna as the antenna pattern. The parabolic taper antenna is a good theoretical alternative for users that do not have actual antenna pattern measurement. When parabolic taper antenna is selected from the drop down menu a new window will pop up as shown in Figure 3. The parabolic taper antenna requires the following input from the user: frequency in MHz, aperture radius in meters, edge illumination in decibels, and pedestal level as shown in Figure 3. The Frequency input textbox in Figure 3 will show ‘NaN (not a number)’ if there was no input entered for frequency input textbox in Main Window of ARPT. The ARPT antenna efficiency values are calculated from user’s input and thus cannot be altered.

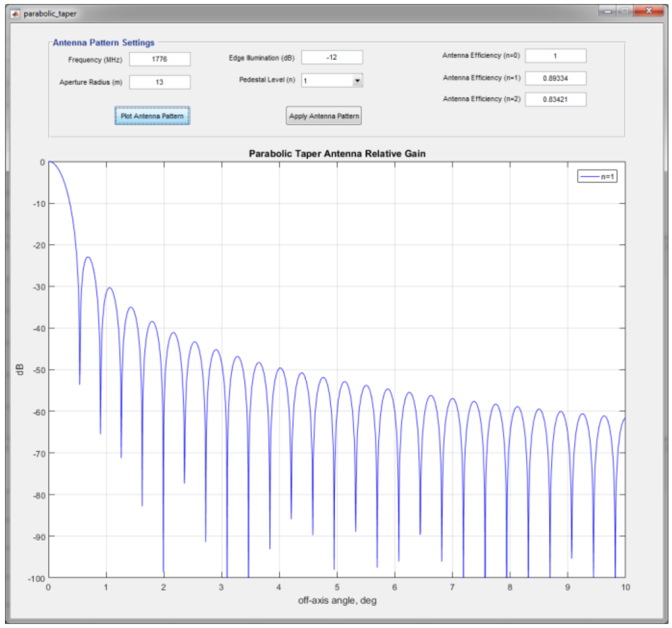

Figure 3. Parabolic Taper Antenna for ARPT

Theory and equations for implementing parabolic taper antenna pattern can be found in the following reference, "Antenna Theory and Design 3rd edition" [5]. It is required that the user understands the basic theory of what each parameter means before using these antenna patterns. The 'All' option in pedestal level is implemented for convenience so that the user can compare all available pedestal levels 0 to 2. It cannot be used as an antenna pattern for the model.

3.2.3 Implementation of Custom Antenna Pattern

Users who prefer to use their own antenna patterns can use this option. The file extension for custom antenna pattern is *.mat. The file format is two columns with size of 7200 values and each column having variable names 'degrees' and 'Gain_dB'. Custom antenna pattern file must be placed inside the 'AntennaPatternData' folder before it can be utilized in ARPT. In order to utilize the file, 'Custom Antenna Pattern' is selected from the drop down menu for antenna pattern and a new window will pop up as shown in Figure 4.

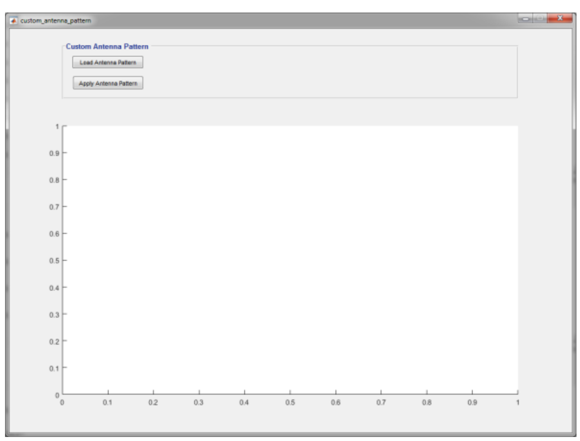

Figure 4. Custom Antenna Pattern Window

File created by the user can be viewed in this window by clicking ‘Load Antenna Pattern’ button and selecting the file that is created by the user. The antenna pattern will be plotted in the window as shown in Figure 5.

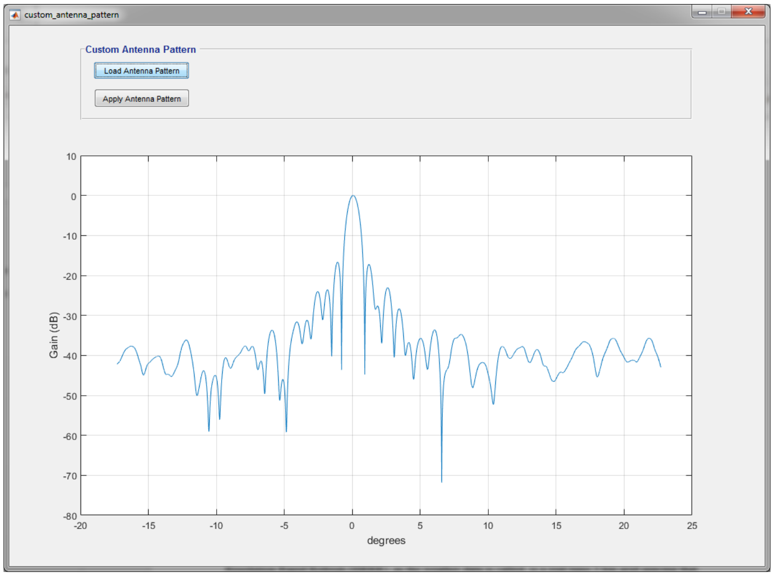

Figure 5. View Custom Antenna Pattern File

To apply the antenna pattern to the propagation tool, ‘Apply Antenna Pattern’ button must be clicked and follow the steps shown in the status window shown in Figure 6.

Figure 6. Status Window after Applying Custom Antenna Pattern

The custom antenna pattern is now ready to be utilized and the user should be back in the main dashboard of ARPT. Readers interested can refer to the following article, “UHF Propagation Prediction in Smooth Homogenous Earth Using Split-step Fourier Algorithm” for implementation details [4].

3.3 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). Using the DTED allows the tool to capture the diffraction due to terrain as closely as possible. 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 must be 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 the transmitter in any step sizes, in kilometers.

3. Column 2: Height above mean sea level, in meters. The height values must correspond directly to the corresponding distance values in column 1. In other words, column 2 data represent the terrain height at the corresponding ranges from 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

Custom terrain files created by users can be used in the tool by placing the files inside the "TerrainData" folder. By clicking the load profile button in Terrain sub-menu, terrain profiles can be loaded. When terrain file is loaded the GUI will look similar to Figure 7.

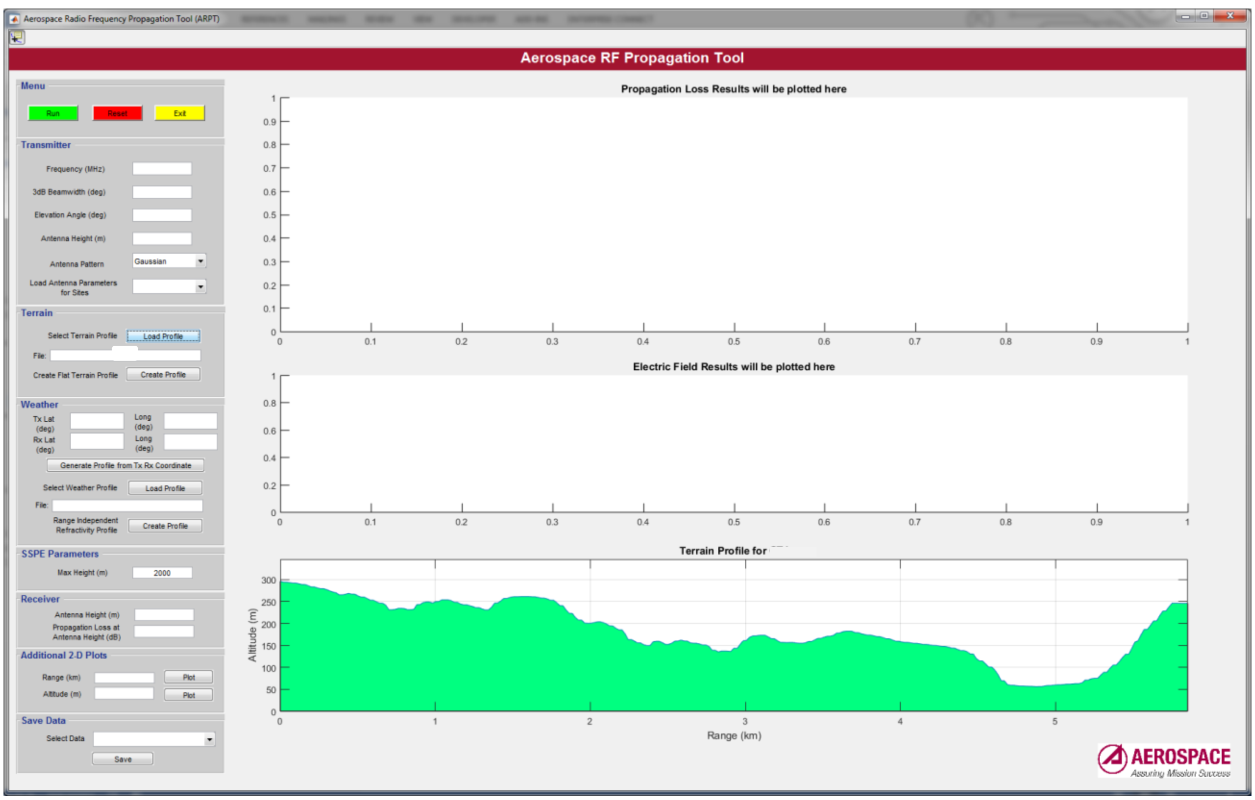

Figure 7. Terrain Profile Loaded

3.4 Weather Data

Weather plays a key role in determining the 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 and then extracted up to 4 km in height, ignoring anything above that.

ARPT primarily uses the index of refraction data extracted from HRRR in predicting path loss. Hence after the 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 the modified index of refraction. If the index of refraction, n, is known, it can be converted to Modified Index of Refraction through the following equation [3]:

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

where z is the height above the surface in meters and a_e is the Earth's radius 6.378 million meters.

    c. Distance from Transmitter (duct_range_array in Matlab) where units are in km
    d. 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 Range Array: each value represents the distance in Km from the transmit antenna, where the vertical weather profile changes. Values for the new weather profile are contained in the same row/column of duct_height_array2 and duct_M_array2 arrays. For example, if entries were [0, 2], the first vertical weather profile is used from 0 km to 2 km and the 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 the example below.
- Duct Height Array: for each range, as described in "Duct Range Array" above, it contains the heights in meters, with respect to mean sea level, at which the "Duct Modified Index Array" is defined.
- Duct Modified Index Array: each entry corresponds to the modified index value at a range and height defined by "Duct Range Array" and "Duct Height Array" respectively.
- Duct Type Array: will be populated with the value 6 which is an internal representation of the 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 the same number of elements.
For example atm1.mat contains the following variables:

duct_type_array2 = [6 6 6 6]

duct_range_array = [0 5 15 23.68]

$$\text{duct\_height\_array2} = \begin{bmatrix} 0 & 200 & 0 & 0 \\ 0 & 10 & 20 & 75 \\ 0 & 50 & 150 & 200 \\ 0 & 100 & 300 & 0 \end{bmatrix}$$

$$\text{duct\_M\_array2} = \begin{bmatrix} 300 & 320 & 0 & 0 \\ 300 & 310 & 290 & 400 \\ 310 & 300 & 340 & 320 \\ 300 & 290 & 340 & 0 \end{bmatrix}$$

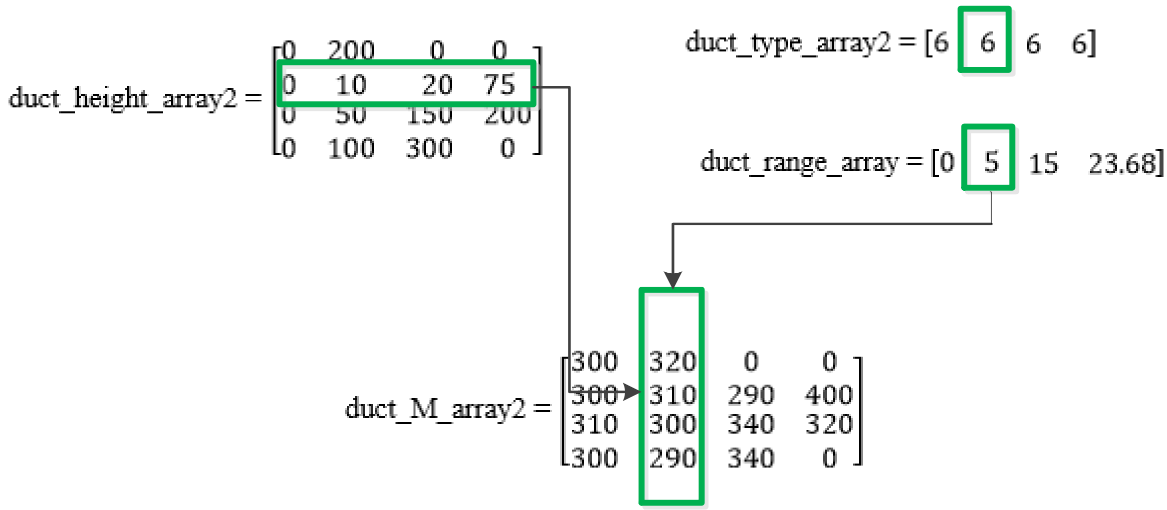

Figure 8. Format of Custom Weather Data

Figure 8 describes how each of the array operates with each other. For example, the 320 value in duct_M_array2 is the modified index of refraction value for range at 5 km with height 200 meters and type value is 6 due to being created by the user. In order to create .mat files, Matlab is required and recommended.

3.4.1 Near Real Time Weather Data

This feature allows the user to use near real-time weather data as long as access to the internet is available. The file obtained from HRRR contains near real time weather data for Contiguous United States (CONUS). The user needs to select the relevant part of data that corresponds to the area of interest as defined by the transmit antenna and receiver coordinates to accurately predict the path loss. The ARPT requires transmitter and receiver coordinates from the user as input to extract the required data. The detailed steps are shown below.

Step 1: Download Data from NOAA.
Download the HRRR from NOAA's website: http://www.ftp.ncep.noaa.gov/data/nccf/com/hrrr/prod/
There is a limitation of data from this website; only two days of data are available, the present date and the day before as shown in Figure 9. Data from further previous dates are not available through this portal of NOAA's website.

Select the date:

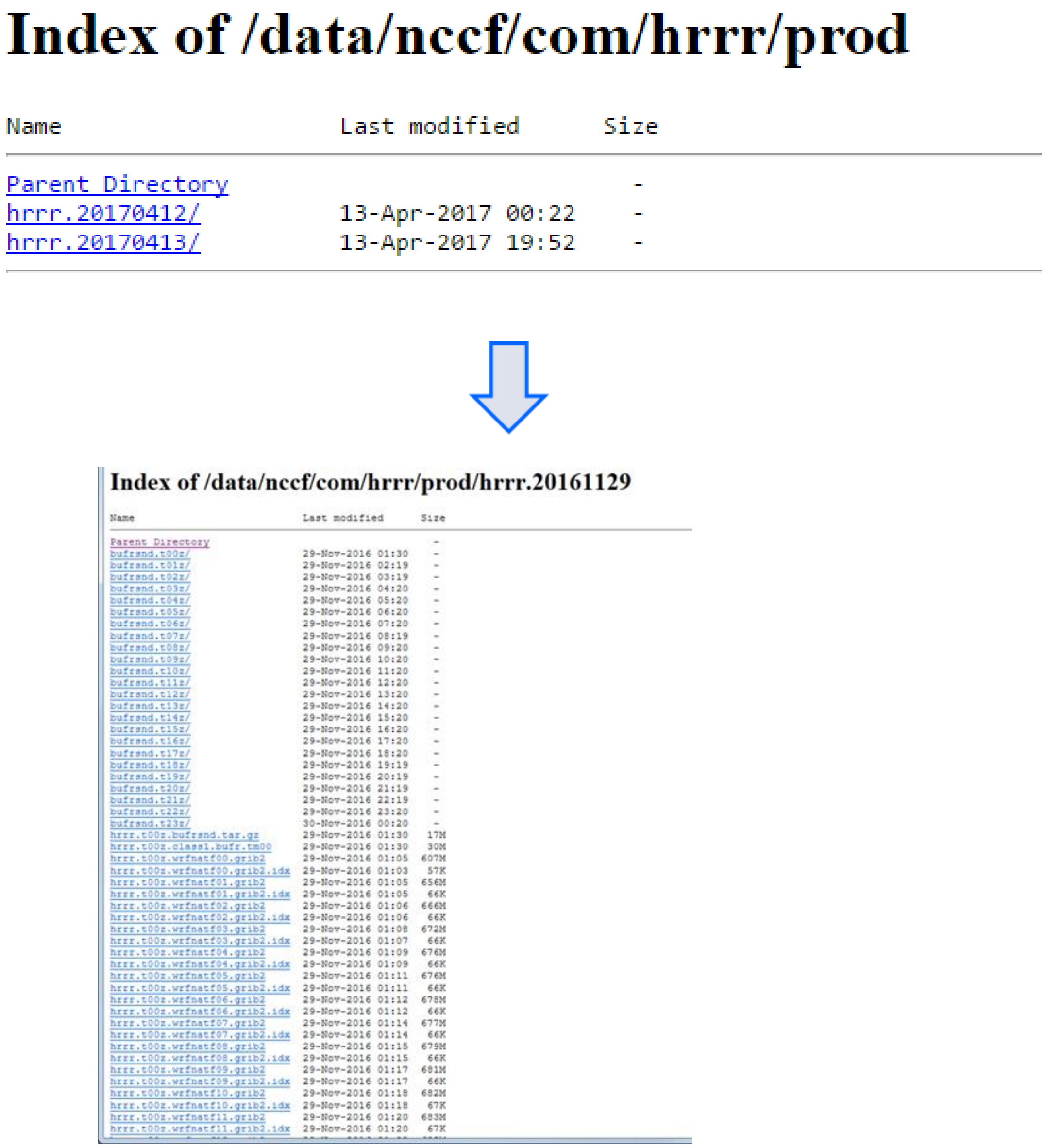

Figure 9. Selecting HRRR File from NOAA Website

Download the HRRR file:
The file name the user should look for is ‘hrrr.txxz.wrfnatf00.grib2’, where xx is UTC time. General Regularly-distributed Information in Binary form or usually referred to as GRIB is a concise data format commonly used in metrology to store and forecast weather data standardized by the World Meteorological Organization (WGO). Save the grib2 file in the main ARPT directory by right clicking on the selected grib2 file and choose “Save Target as” as shown in Figure 10.

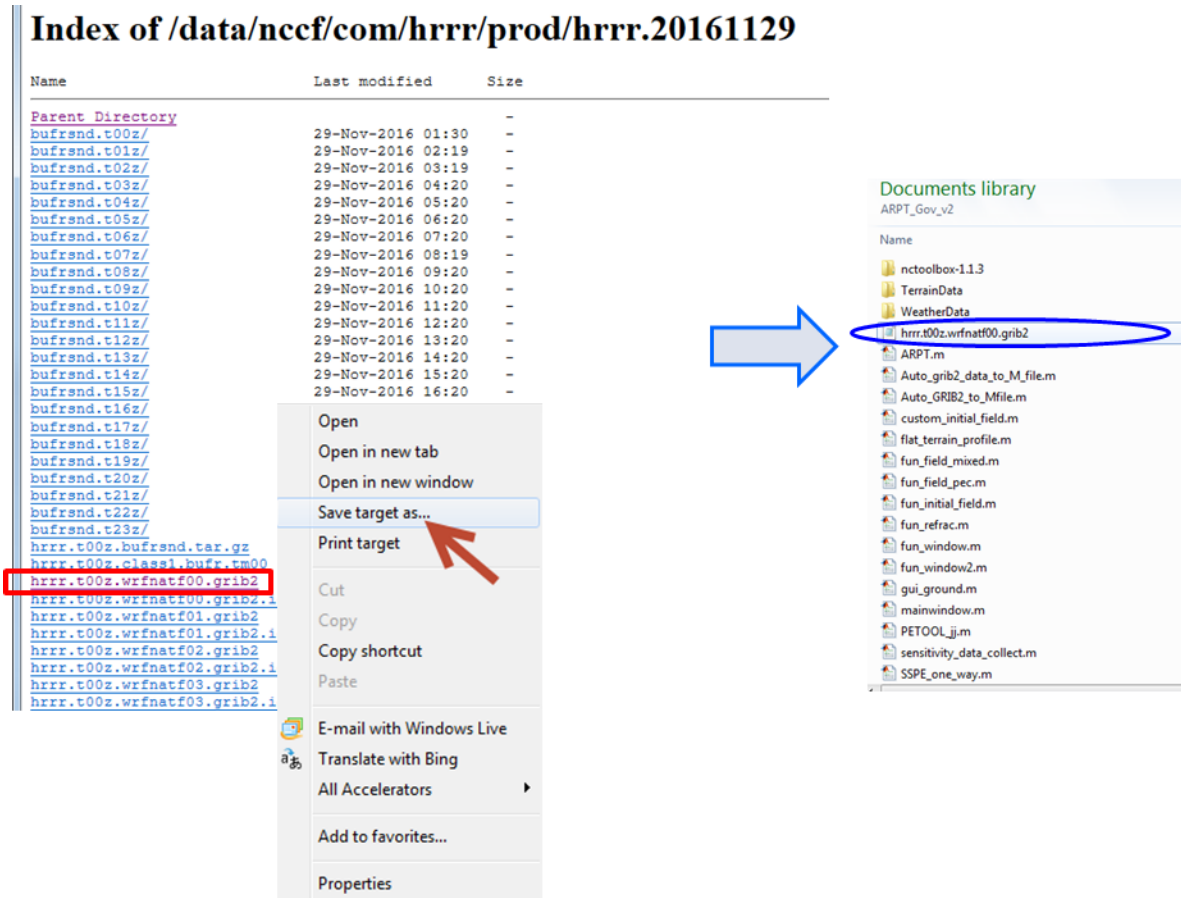

Figure 10. Downloading HRRR GRIB2 File

Step 2: Use HRRR data in ARPT

The file obtained from HRRR contains weather data for the whole continental US (or whatever the region might be). The user needs to select the part of data that corresponds to the area of interest as defined by the transmit antenna and receiver coordinates.

In ARPT Weather menu, enter transmitter and receiver latitude and longitude coordinates in decimal format as shown in Figure 11. It is essential that the distance between transmitter and receiver coordinates matches the terrain profile that will be used in the simulation. For example, if the distance between transmitter and receiver is 5 km then the terrain profile must also be 5 km. If the terrain profile only covers 10 km while weather data generated using GRIB2 file was 20 km then the tool will not perform the calculation. Next, select the grib2 file by clicking ‘Generate Profile from Tx Rx Coordinate’. After the grib2 file is selected, ARPT will auto generate the index of refraction from HRRR grib2 file and store the file in the weather folder of ARPT directory with file name convention of the following form: HRRR_Weather_Data _Current_Date_Time.

For example, “HRRR_Weather_Data_01_Feb_2017_15_03_18.mat”. To utilize the file for simulation, the file must be selected by clicking the load profile button in the Weather sub-menu.

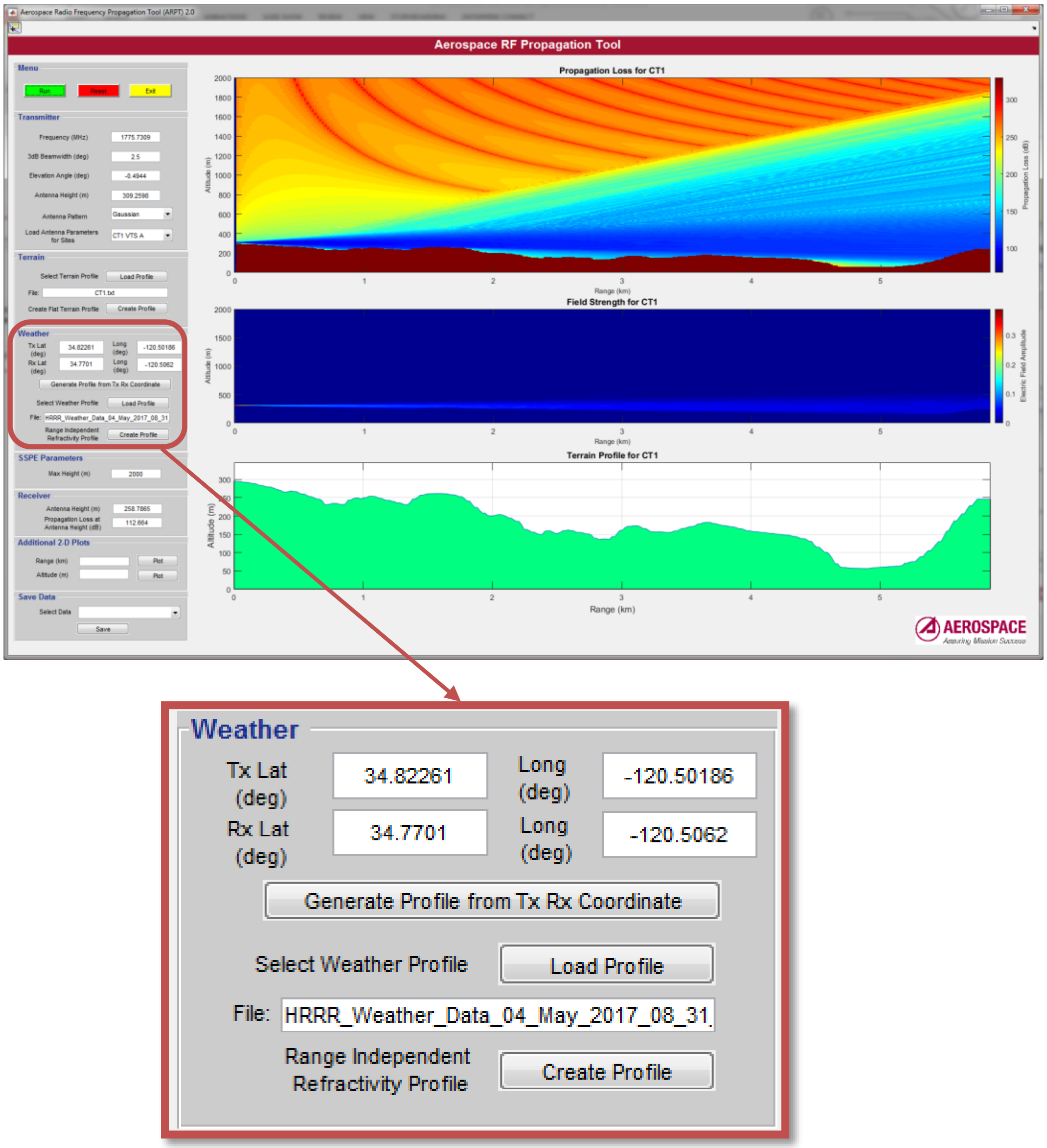

Figure 11. Input for Lat and Long in ARPT

3.5 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 overextend above the weather data. In addition, the 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 is between 2000 to 2500 meters and it is strongly recommended to stay within these ranges.

3.6 Receiver Information

The receiver information consists of the height at which the receiver antenna is placed above sea level in meters. Receiver height should be known by the user to determine the path loss approximately at the receiver height. Resolution of step height is dependent on wavelength which is dependent on the frequency of interest hence, the tool simulates and produces path loss results near receiver height more accurately with higher frequencies.

3.7 Calculating Path Loss

In order for ARPT to calculate path loss all of the inputs must be entered as summarized below.

1. The user must enter the following required parameters before the tool can predict the path loss.
   a. Transmitter Information
      i. Signal Frequency in MHz.
      ii. 3dB Beamwidth in degrees.
      iii. Elevation angle of the antenna in degrees.
      iv. Transmitter antenna height above mean sea level in meters.
      v. Antenna pattern options are: Gaussian, parabolic taper, and custom antennas where the default is Gaussian antenna pattern.
   b. Weather Information
      i. Weather file should be selected by clicking the Load Profile button; upon clicking another window will open, where the user can select the desired weather profile.
      ii. If HRRR file is used to extract near real-time weather data, latitude and longitude boxes for transmitter and receiver must be entered.
   c. Terrain Information
      i. 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.)
   d. SSPE Parameters
      i. Max Height needs to be entered by the user and it should be greater than or equal to 2000 meters and less than 2500 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 2000 to 2500 meters.)
   e. Receiver Information
      i. Receiver antenna height above mean sea level in meters should be entered.

2. Press the green “Run” button in the Menu section shown in Figure 12 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 13. It should be noted, that since weather data resolution is less coarse than the terrain profile, the last column of weather profile will be used for the remaining distances. The 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, weather profiles, max height, and the CPU speed.

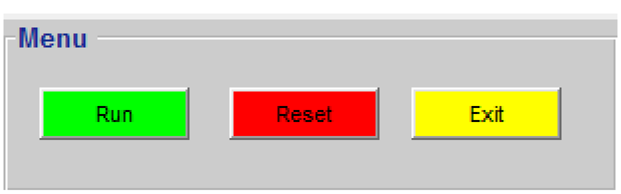

Figure 12. Menu Section

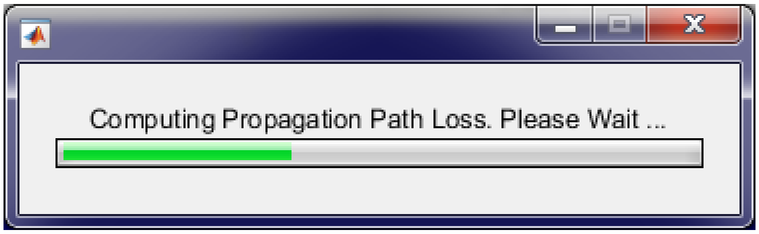

Figure 13. Wait Box

3. After the message box disappears, the Path Loss and Field Strength plots will be populated as shown in Figure 14.

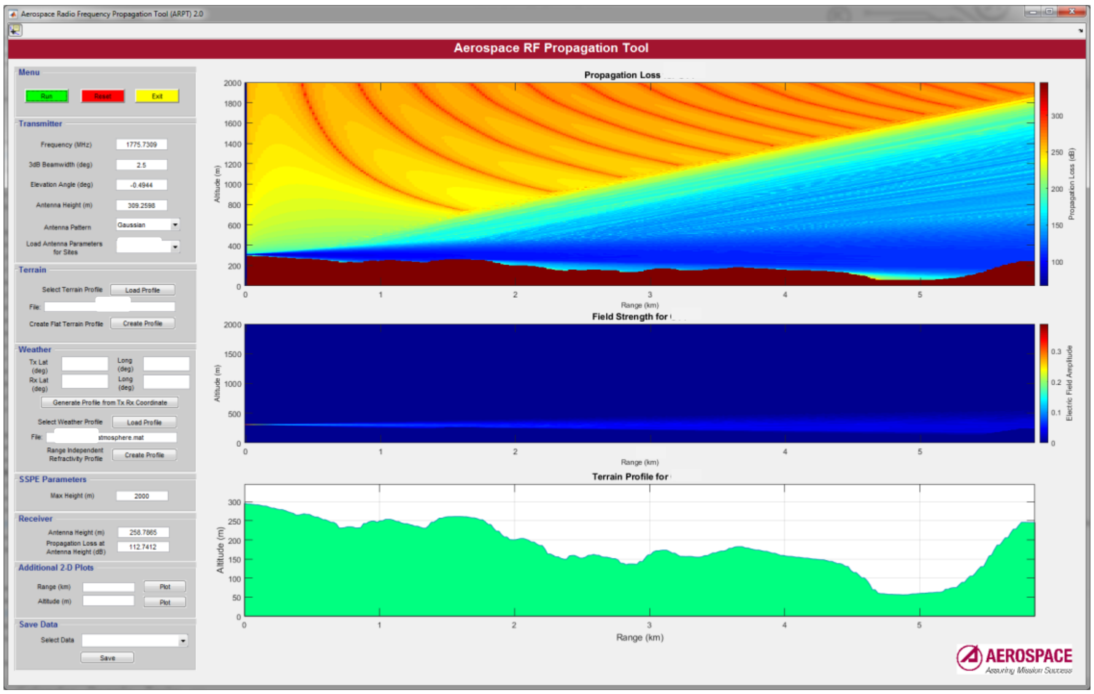

Figure 14. Path Loss Calculation Completed

4. The user can see the values in the images by left clicking on all of the plots shown in Figure 14.

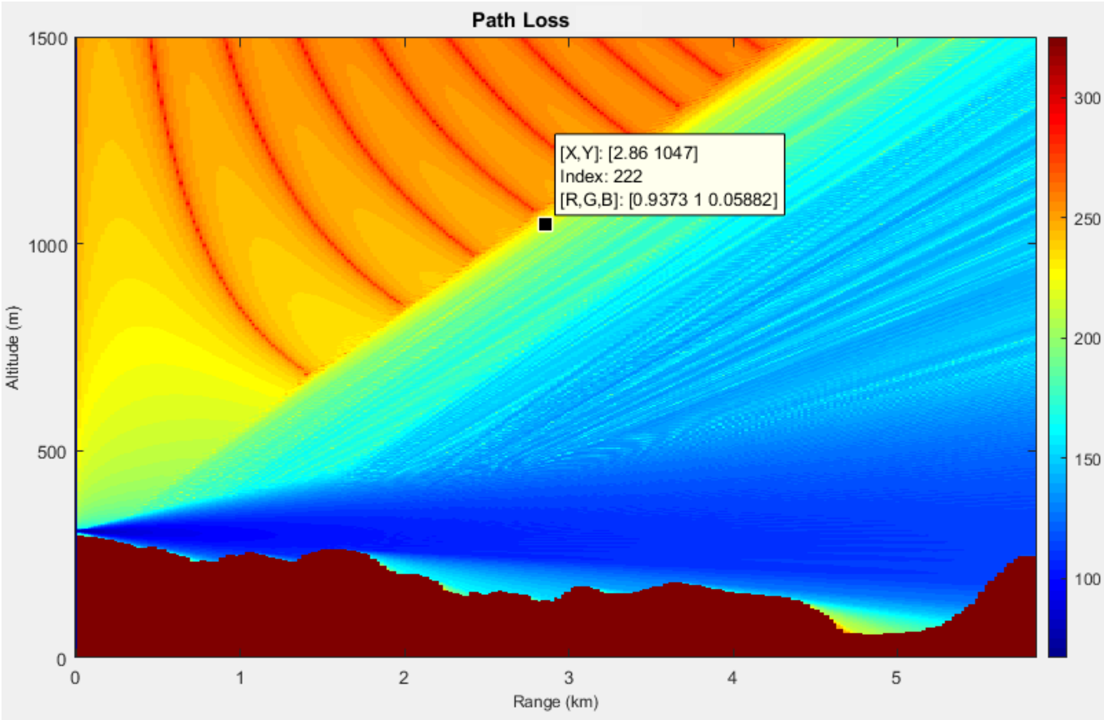

Figure 15. Path Loss Plot

For example, as shown in Figure 15, by left clicking on the plot itself, information for that particular point will be displayed. The "[X, Y]" entry corresponds to the range in kilometers and height above mean sea level accordingly whereas the "Index" entry corresponds to path loss in dB; hence for Figure 15 the tooltip indicates that at that particular point, path loss is 222 dB at 2.86 km in range with 1047 meters height above mean sea level.

5. To create multiple data cursor information boxes, the 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 16. 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 respectively.

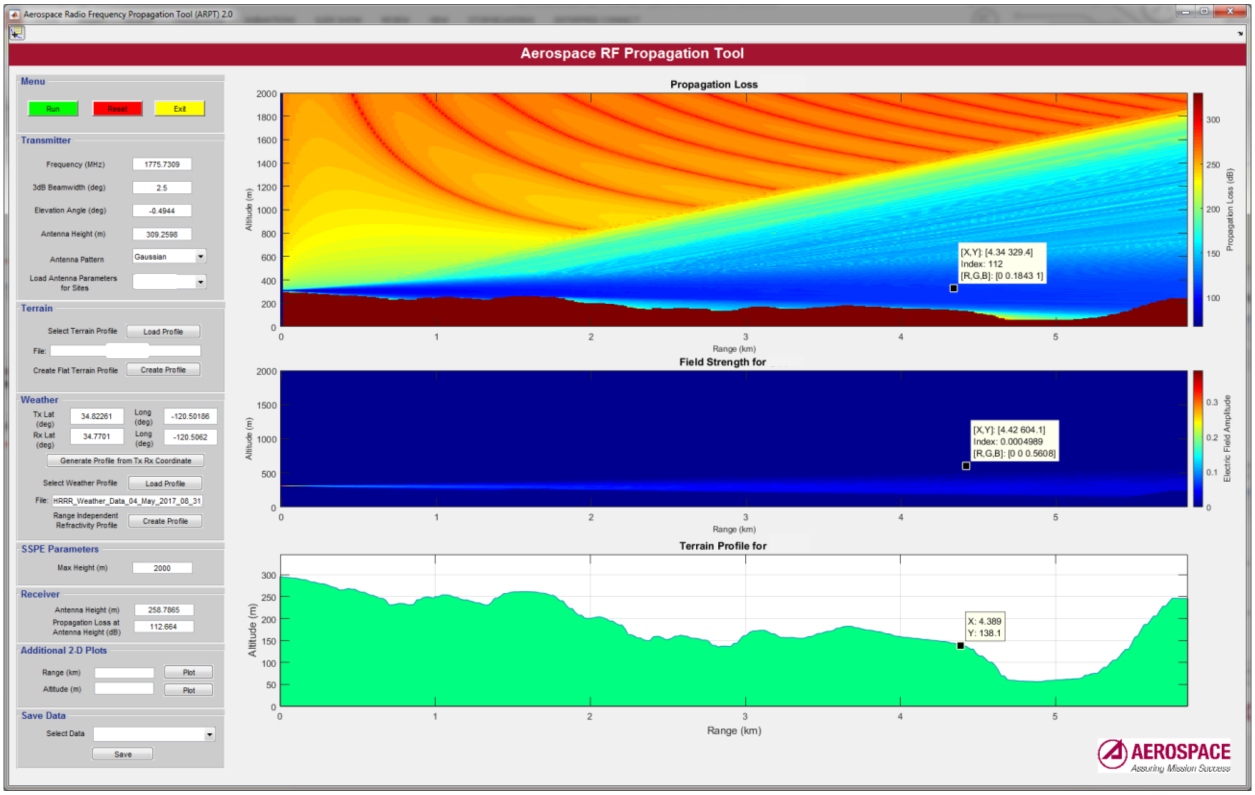

Figure 16. Multiple Data Tips

6. Creating many data tips to view each data can become a problem hence if the 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 the user can utilize the “Additional 2-D Plots” section in the menu.
   a. The user can enter an altitude value and click the plot button to the right of the input box to see the plot similar to shown in Figure 17. The plot will show two curves: one representing the free space loss and the other represents propagation loss.

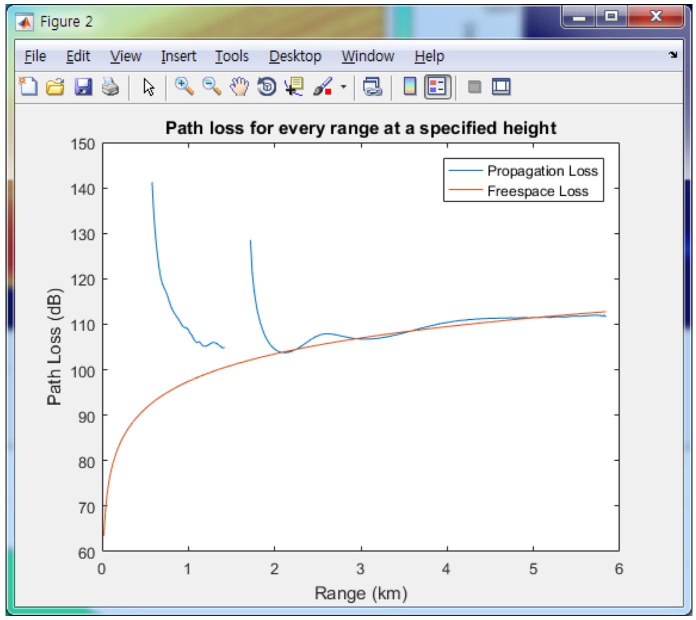

Figure 17. Path Loss for Every Range at a Specified Height

b. The user can enter a 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 18. 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.

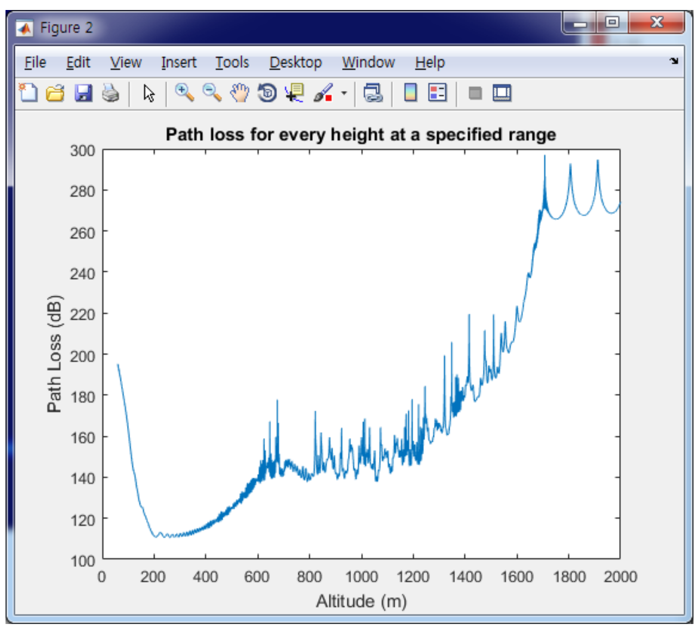

Figure 18. Path Loss for Every Height at a Specified Range

Data tip can be placed for both Figure 17 and Figure 18 by clicking on the data cursor which is shown in Figure 19.

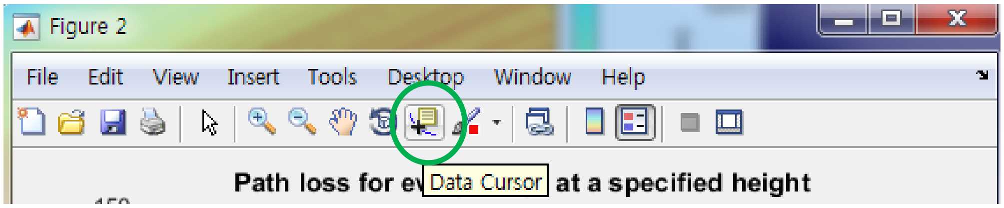

Figure 19. Data Cursor

Before new scenarios are run, the 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.

7. To save the actual values instead of plots, the last menu that is placed at the bottom, "Save Data" can be utilized. The user can select "Path Loss" and then click "Save" button to save the data as shown in Figure *20*. The path loss data is in Comma Separated Value (CSV) format and it contains all the path loss data between transmitter and receiver as a function of height and range.rr

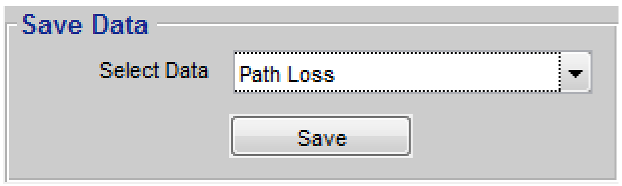

Figure 20. Save Path Loss Data

8. To clear all the input parameters except terrain and weather profiles, the user can click the "Reset" button colored in red on the menu section.
9. To exit the GUI, the user can click the "Exit" button colored in yellow on the Menu section.

4. Other Operations

Previous sections showed how to operate the tool with an underlying assumption that terrain and weather profiles were already created and 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 the user did not have any terrain and weather profiles to load into the tool, a simple flat terrain with range independent refractivity weather profiles can be used.

4.1 Create Flat Terrain Profile

When create profile button is clicked in the terrain sub-menu a new window will pop up as shown in Figure 21.

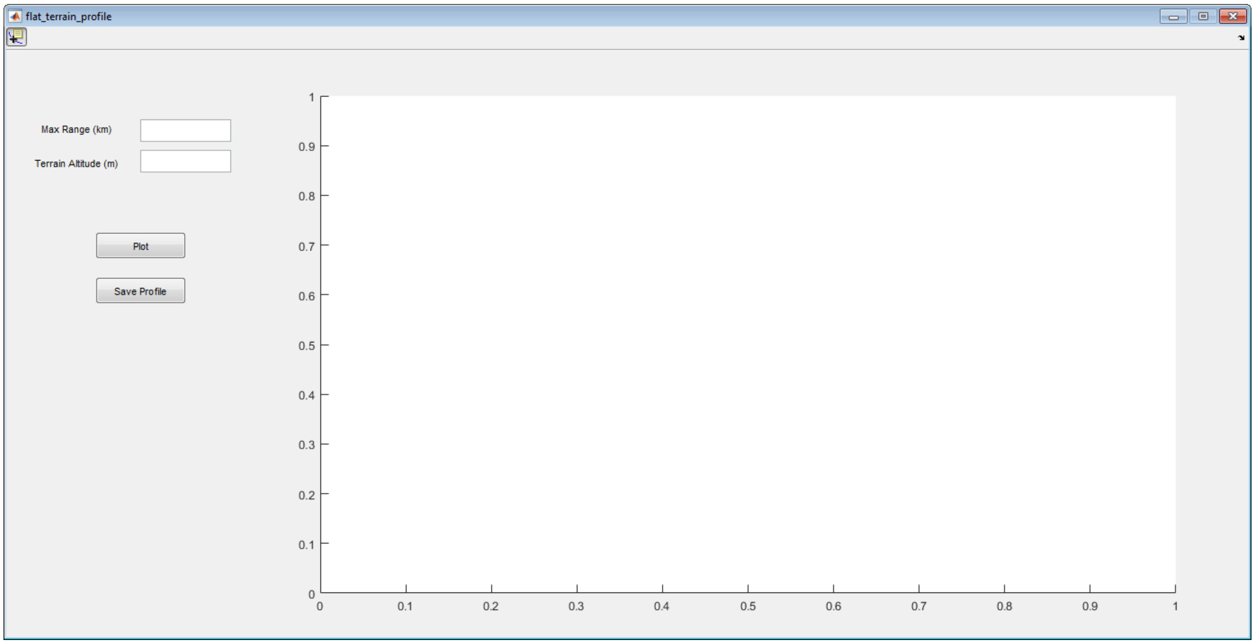

Figure 21. Create Flat Terrain Profile Window

To create a flat terrain, the user enters the maximum end range and the flat terrain altitude in meters. The user can verify the terrain by pressing the plot button and flat terrain file will be plotted as shown in Figure 22.

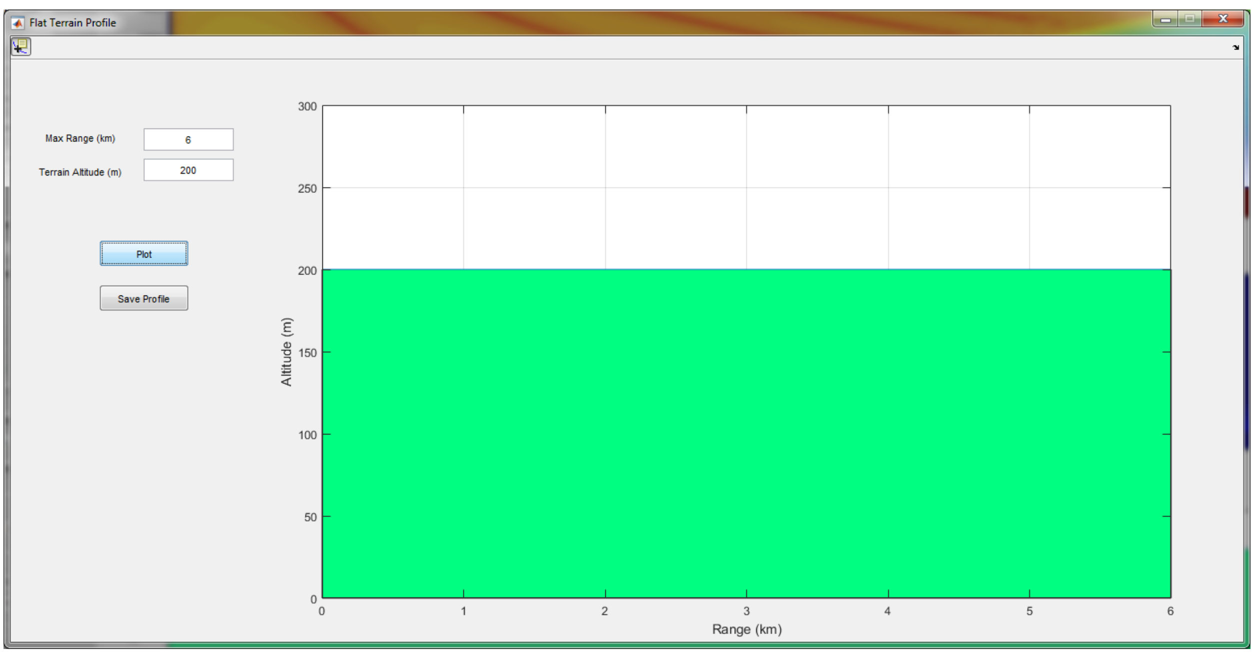

Figure 22. Flat Terrain

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”.

4.2 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 and plotted as shown in Figure 23 then 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”.

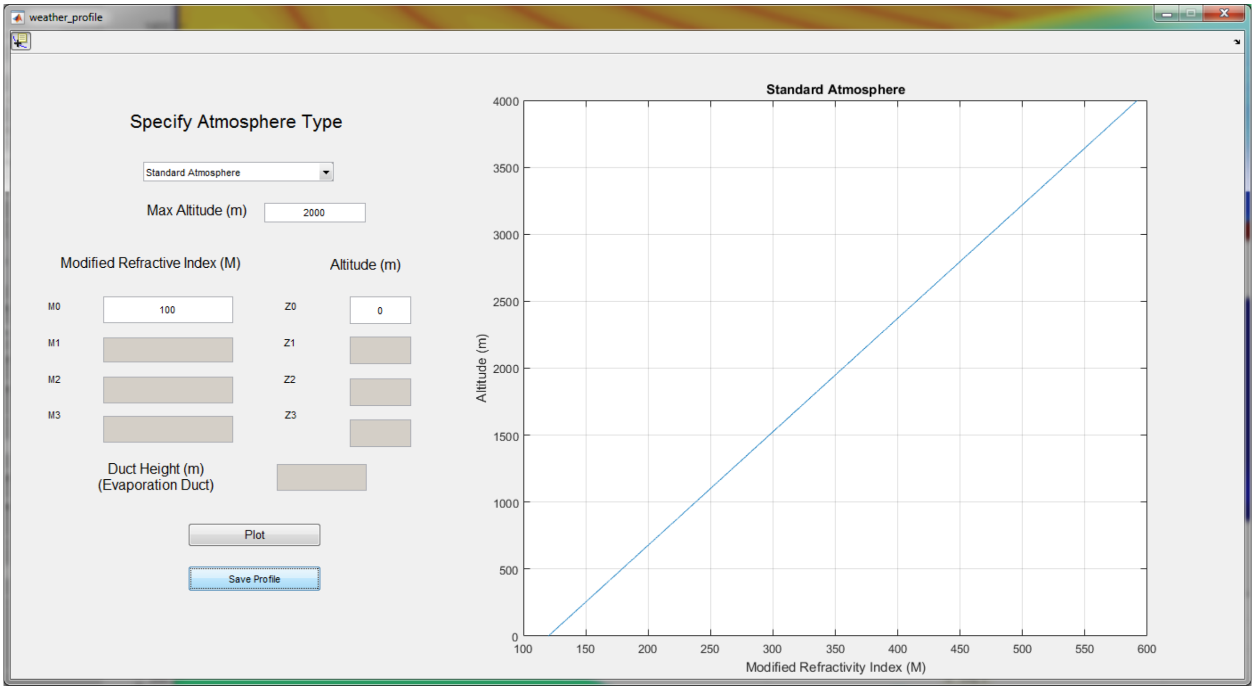

Figure 23. Create Range Independent Refractivity Profile

By loading two profiles “flat_terrain.txt” and “Standard_Atmosphere.mat”, Figure 24 is the final outcome.

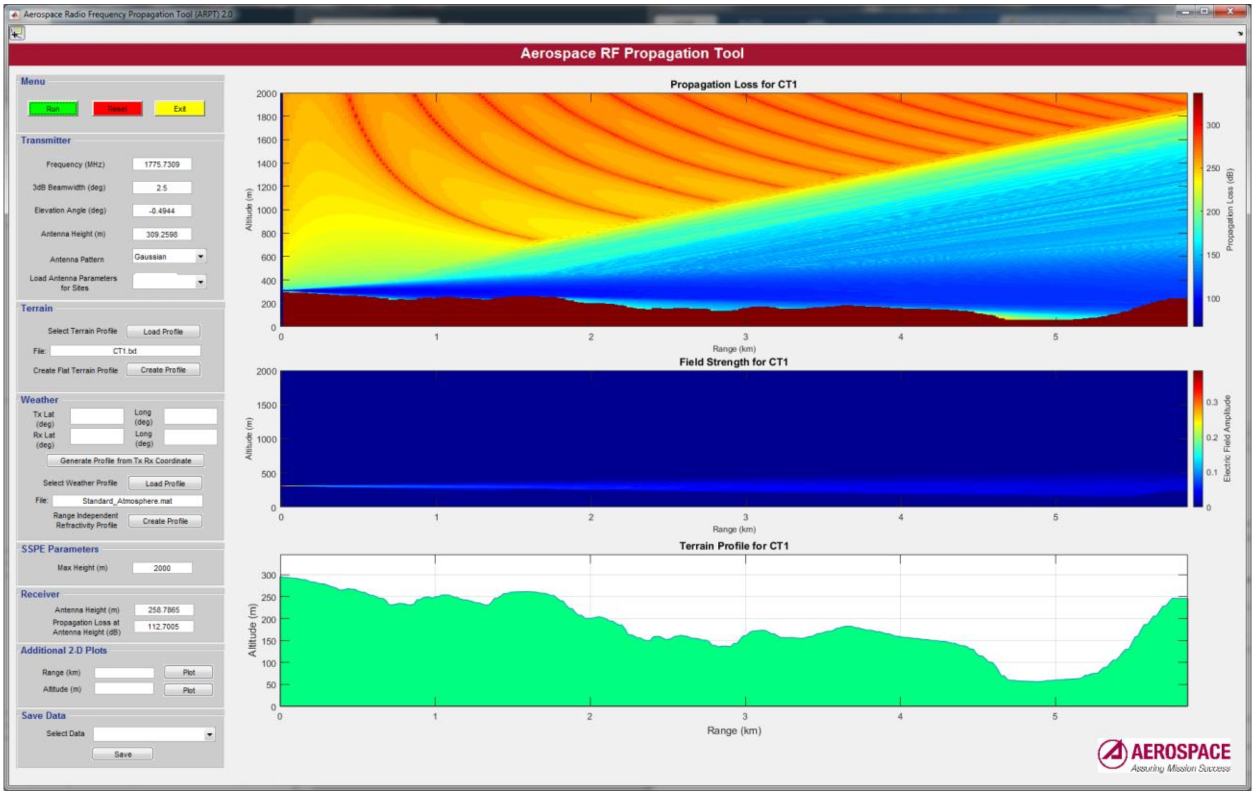

Figure 24. Using Flat Terrain and Range Independent Weather Profile

5. Compatibility between ARPT and Weather Data

ARPT 2.0 as of this writing works only with HRRR GRIB2 file from NOAA. This is the case due to the file being able to provide sufficient weather data for CONUS. However, ARPT is not restricted to one type of weather data and others from different organizations such as European Centre for Medium-Range Weather Forecasts (ECMWF) can be integrated with ARPT. Please contact The Aerospace Corporation for additional requests and questions.

6. Disclaimer

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8. Acronyms

2-D	Two-dimensional
ARPT	Aerospace RF Propagation Tool
CONUS	Contiguous United States
CPU	Central Processing Unit
DTED	Digital Terrain Elevated Data
ECMWF	European Centre for Medium-Range Weather Forecasts
GRIB	General Regularly-distributed Information in Binary form
GUI	Graphical User Interface
OS	Operating System
FSS	Fourier Split-Step
HRRR	High Resolution Rapid Refresh
NOAA	National Oceanic and Atmospheric Administration
SSPE	Split Step Parabolic Equation
TIZ	Transmit Inhibit Zone
WMO	World Meteorological Organization

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