High-Frequency Signal Strength Modeling at GRAPE Personal Space Weather Stations Using PHaRLAP Ray Tracing

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Objectives

- *Regenerating* a successful reception on April 8, 2001, 7 UTC @5,10 and 15 MHz
  from WWV, Colorado to W2NAF Spring Brook, Scranton
- *Understanding* the Total Absorption Loss profile for each HF ray.
- A dream: *Developing* PyLAP (D-Region & during eclipses) -> a good model for signal strength.

A Good Learner is a Good Developer!

Special Thanks

Special thanks to Prof. Nathaniel A. Frissell (W2NAF), lead of the Ham Radio Science Citizen Investigation (HamSCI).

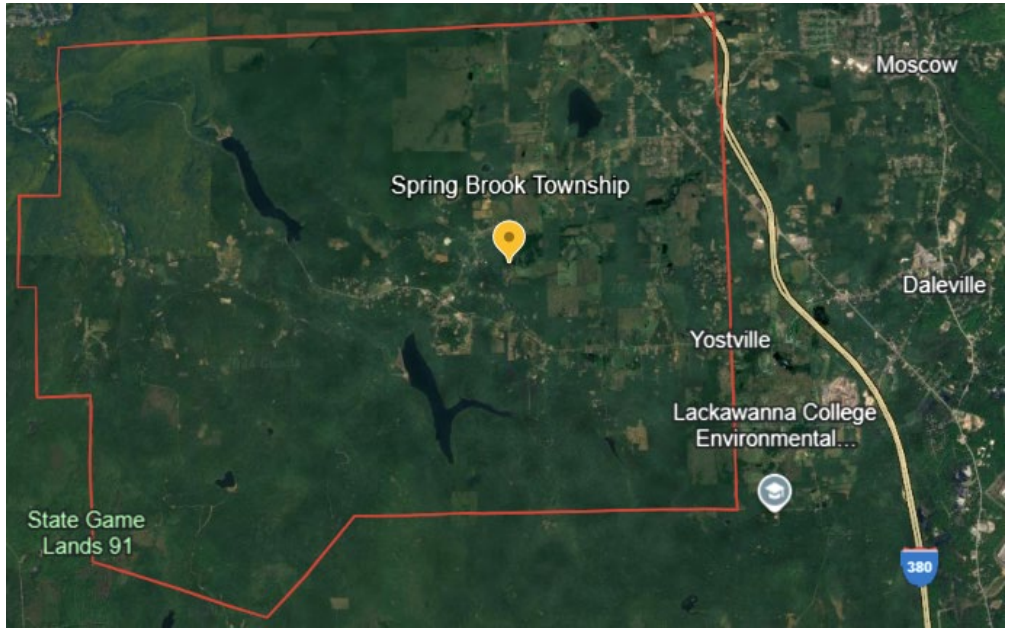
Special thanks to David McGaw N1HAC (Dartmouth College), Mr. Gary Mikitin (AF8A), Radio Operators Expert, and Mr. Bill Liles (NQ6Z), HamSCI Community Diversity Recruitment Chair, and Case Western Reserve University in collaboration with the University of Scranton for their invaluable contributions. Special thanks for the financial support of U.S. National Science Foundation Grant AGS-2404997 and Amateur Radio Digital Communications (ARDC).

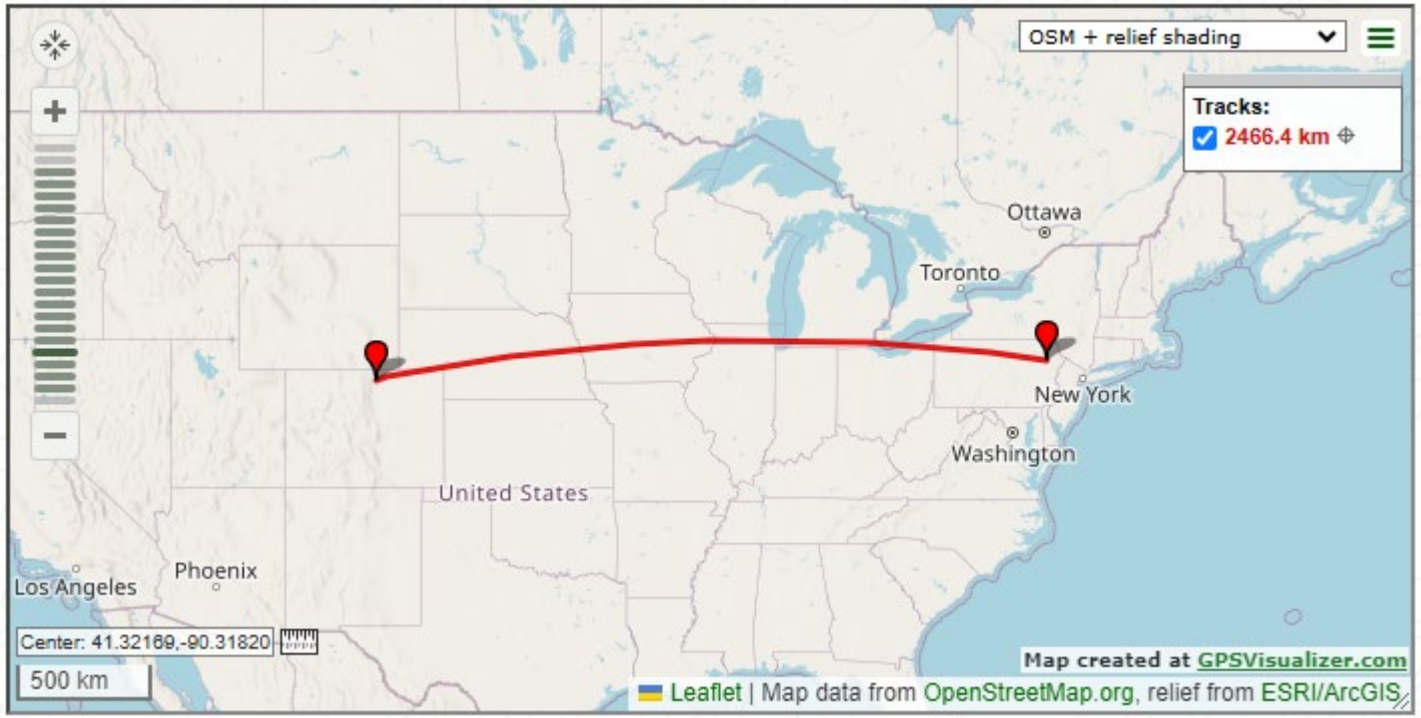
From WWV (Fort Collins, Colorado)

- Latitude: 40.6758
- Longitude: -105.0389

WWV - Callsign Lookup by QRZ Ham Radio, [15]

To Spring Brook, Pennsylvania (PA), USA





[16] https://www.gpsvisualizer.com/display/map/20241101135441-47194-map.html

Calculate the great circle distance between two points

This calculator will find the distance between two pairs of coordinates to a very high degree of precision (using the thoroughly nasty Vincenty Formula, which accounts for the flattened shape of the earth). The "Draw map" button will show you the two points on a map and draw the great circle route between them.

Lat., Lon. 1: 40.6758, -105.0385

Lat., Lon. 2: 41.3076, -75.5975

—>

2466.436 k
1532.572 r
1331.769 r

78.629° initial bearing (approximate)

Draw map

output format: Leaflet map

units: km

Bearing Calculation:

```
bearing_deg =

   78.6291


Example of 2D numerical raytracing for a fan of rays for a WGS84 ellipsoidal Earth

The distance between WWV and Spring Brook is 2466.4363 kilometers.
Generating ionospheric grid... Elapsed time is 6.238413 seconds.
Generating 31 2D NRT rays ...Elapsed time is 0.042078 seconds.
Extracting ray path data ...
```

Calculate the great circle distance between two points

This calculator will find the distance between two pairs of coordinates to a very high degree of precision (using the thoroughly nasty Vincenty Formula, which accounts for the flattened shape of the earth). The "Draw map" button will show you the two points on a map and draw the great circle route between them.

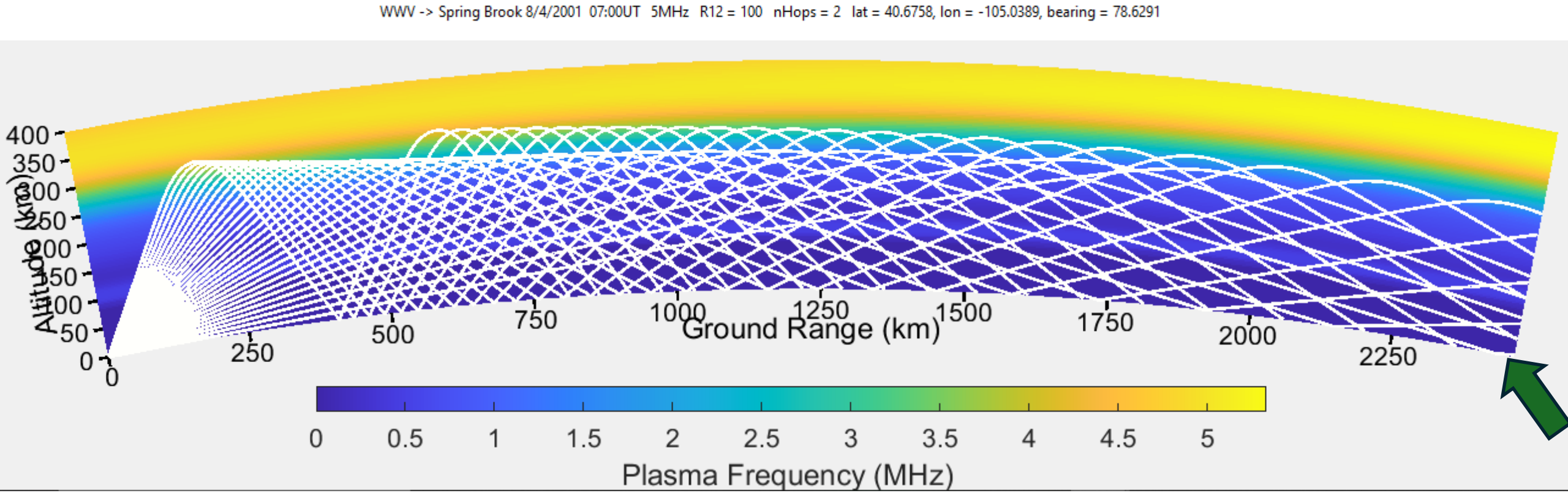
Lat., Lon. 1: 40.6758, -105.0389 —> 2466.436 km, 1532.572 mi, 1331.769 nm, 78.629° initial bearing (approximate)

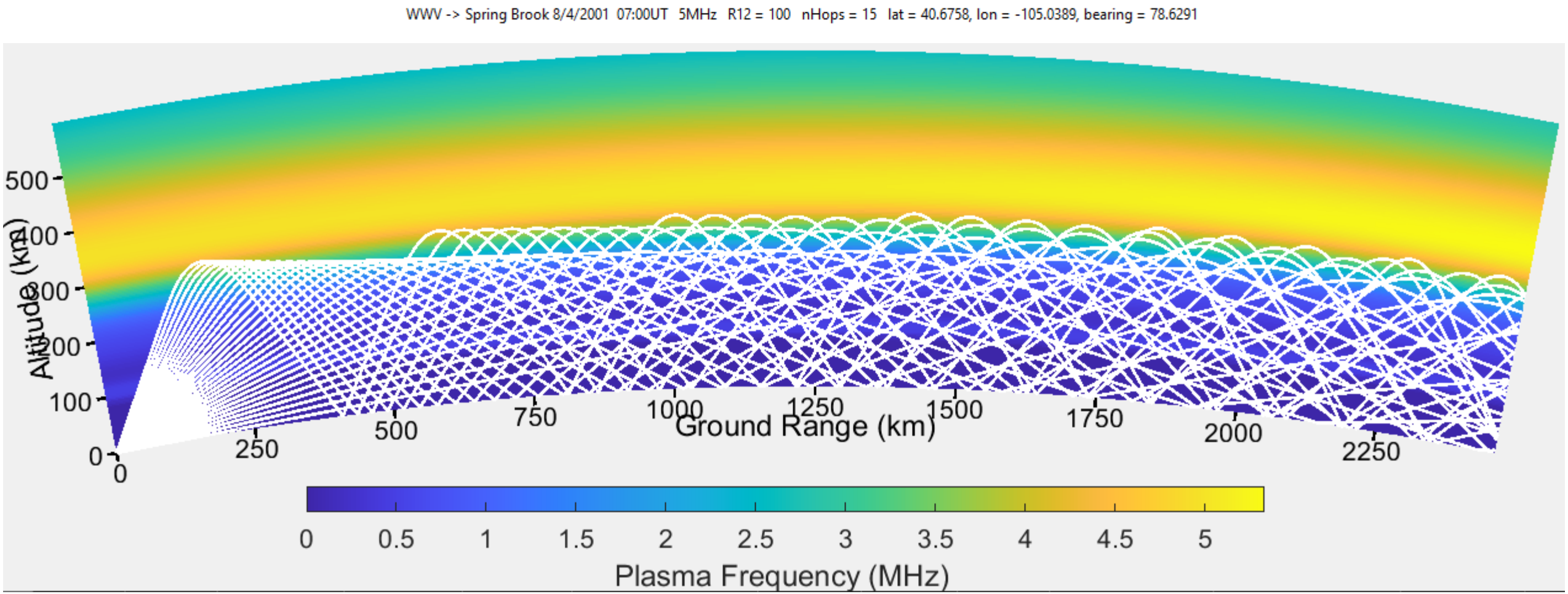
Lat., Lon. 2: 41.3076, -75.5975

Draw map | output format: Leaflet map | units: km

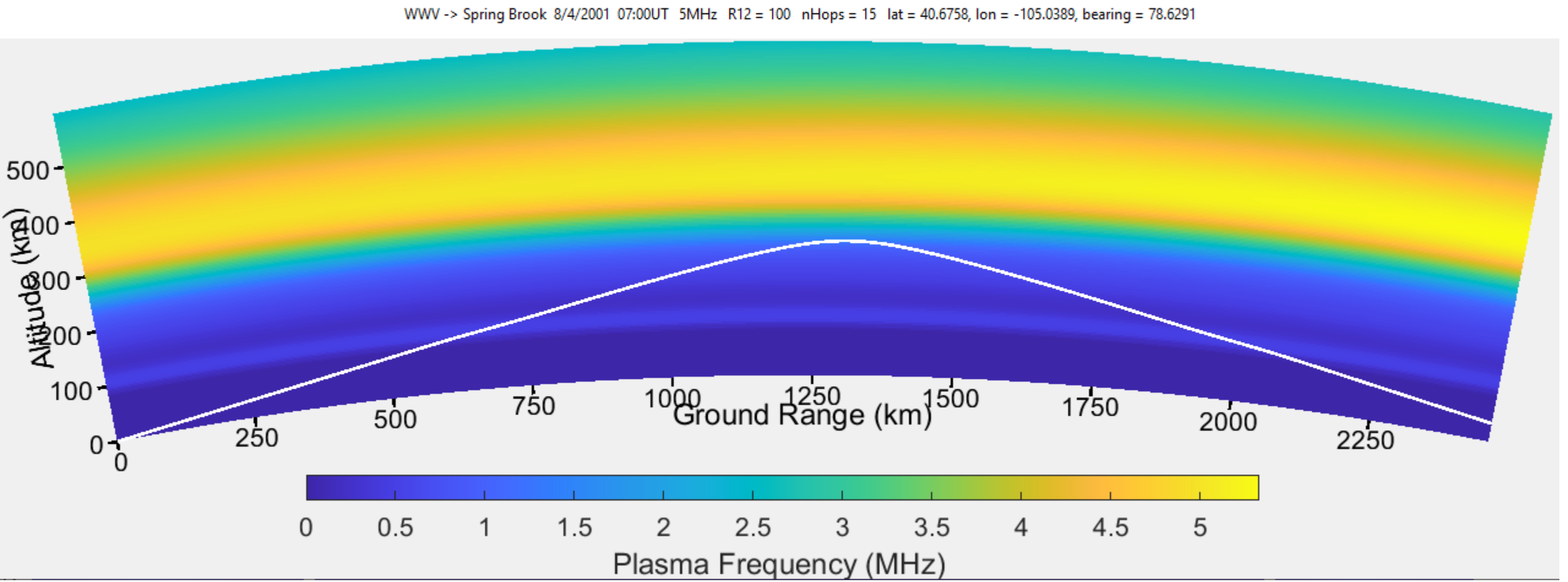
[14] https://www.gpsvisualizer.com/display/map/20241018114723-35166-map.html?center=-4.854,36.093245&zoom=2

- The distance between WWV and Spring Brook is 2466.4363 kilometers.
- Searching for elevation angle = 6 deg. (Manually ☹)

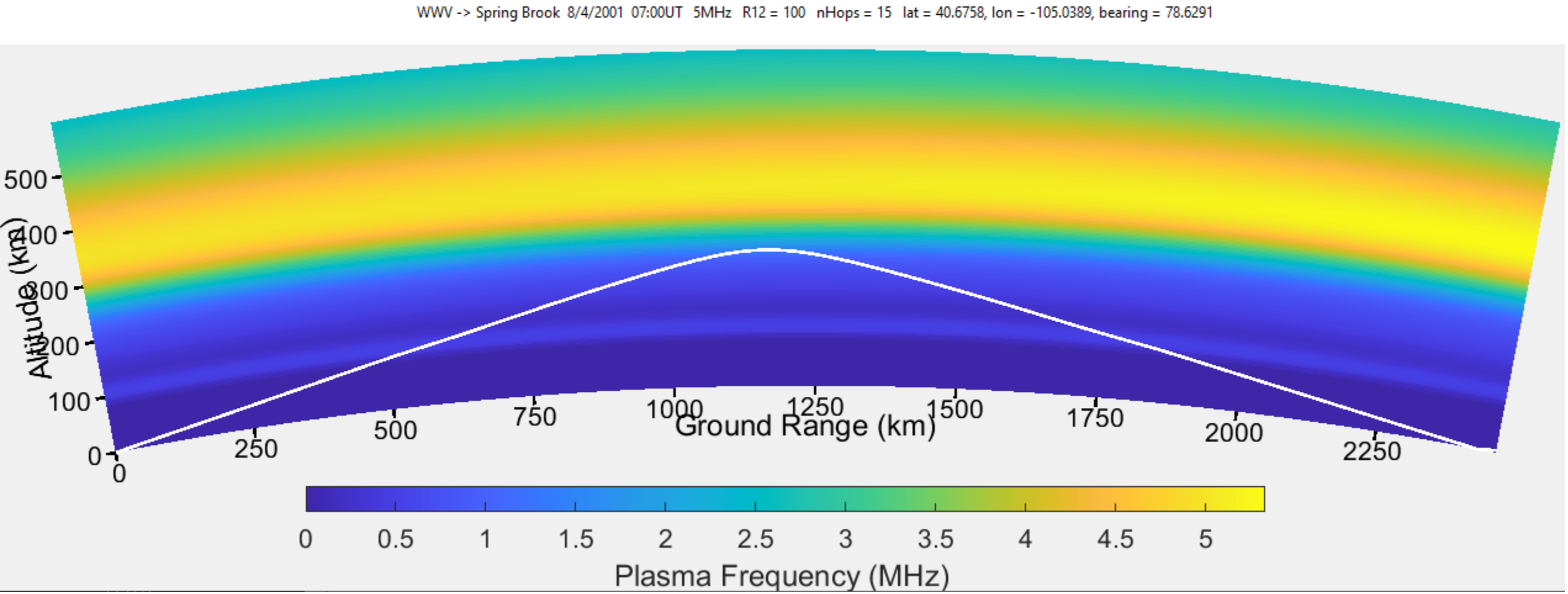



WWV -> Spring Brook 8/4/2001 07:00UT 5MHz R12 = 100 nHops = 15 lat = 40.6758, lon = -105.0389, bearing = 78.6291
Altitude (km)
0
100
200
300
400
500
0
250
500
750
1000
1250
1500
1750
2000
2250
Ground Range (km)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Plasma Frequency (MHz)

Choosing this 6 deg. Elevation: That was so close!



Best ray @5MHz, elevation = 8 deg.



- Ray Data for the 8 deg. Elevation
  Source: WWV
  Dest.: Spring Brook

Field	Value
lat	[41.3662,41.3035]
lon	[284.0029,284.5899]
ground_range	[2.4324e+03,2.4820e+03]
group_range	[2.5408e+03,2.5908e+03]
phase_path	[2.5097e+03,2.5597e+03]
geometric_path_length	[2.5251e+03,2.5751e+03]
initial_elev	[8,6.6004]
final_elev	[6.6004,NaN]
apogee	[241.2539,NaN]
gnd_rng_to_apogee	[1.1702e+03,NaN]
plasma_freq_at_apogee	[1.4718,NaN]
virtual_height	[274.8889,NaN]
effective_range	[1.7556e+06,NaN]
total_absorption	[2.0814,2.0814]
deviative_absorption	[0.0525,0.0525]
TEC_path	[9.4141e+15,9.4141e+15]
Doppler_shift	[-0.0058,NaN]
Doppler_spread	[0,NaN]
FAI_backscatter_coeff	[NaN,NaN]
FAI_altitude	[NaN,NaN]
FAI_range	[NaN,NaN]
FAI_group_range	[NaN,NaN]
FAI_latitude	[NaN,NaN]
FAI_longitude	[NaN,NaN]
frequency	5
nhops_attempted	2
ray_label	[1,-3]
NRT_elapsed_time	0.0050

The distance between WWV and Spring Brook is 2466.4363 kilometers

Makes sense!

Why did the cumulative ionospheric absorption got steady after the 222 distance sample? *Investigating…*

ray_path_data.ground_range

	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230
1	1.8355e+03	1.8425e+03	1.8464e+03	1.8503e+03	1.8600e+03	1.8696e+03	1.8757e+03	1.8837e+03	1.8886e+03	1.8983e+03	1.9050e+03	1.9147e+03	1.9216e+03	1.9221e+03	1.9264e+03	1.9361e+03	1.9451e+03	1.9549e+0

ray_path_data.absorption

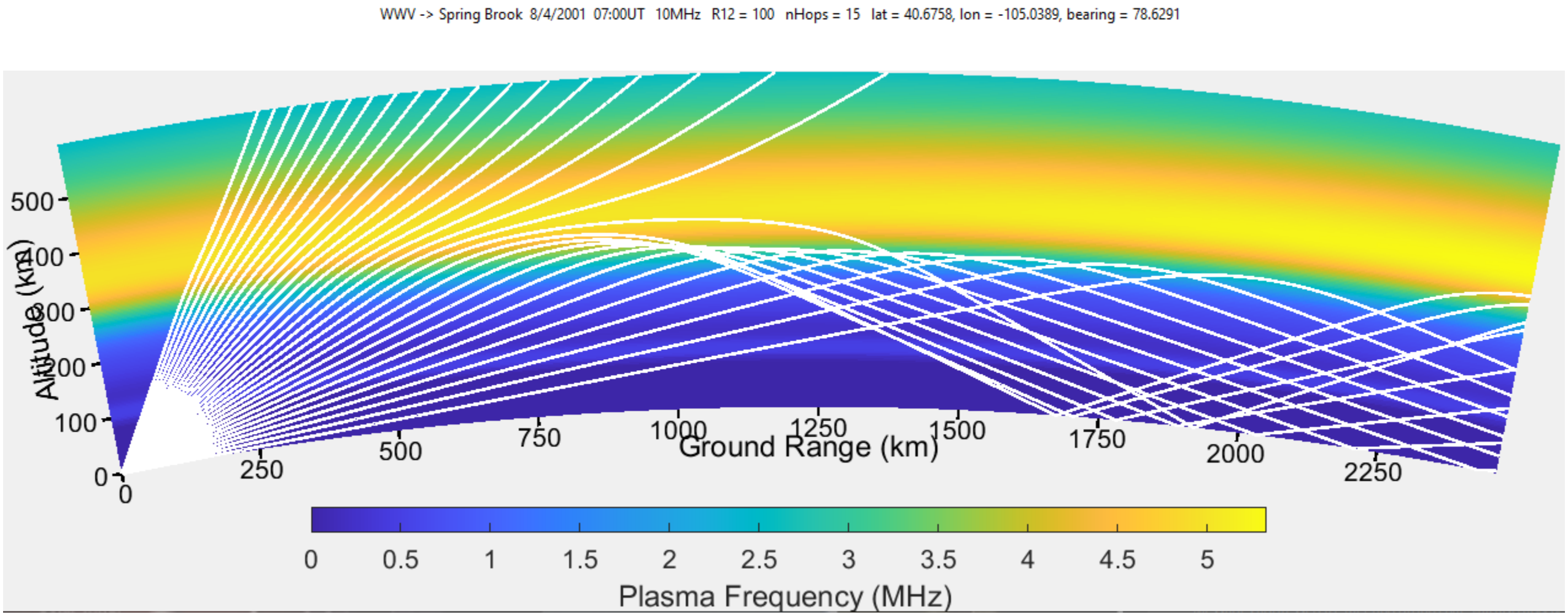
	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231
1	1.4598	1.5087	1.5587	1.6801	1.7835	1.8317	1.8919	1.9362	2.0282	2.0814	2.0814	2.0814	2.0814	2.0814	2.0814	2.0814	2.0814	2.0

Total (Cumulative) Absorption

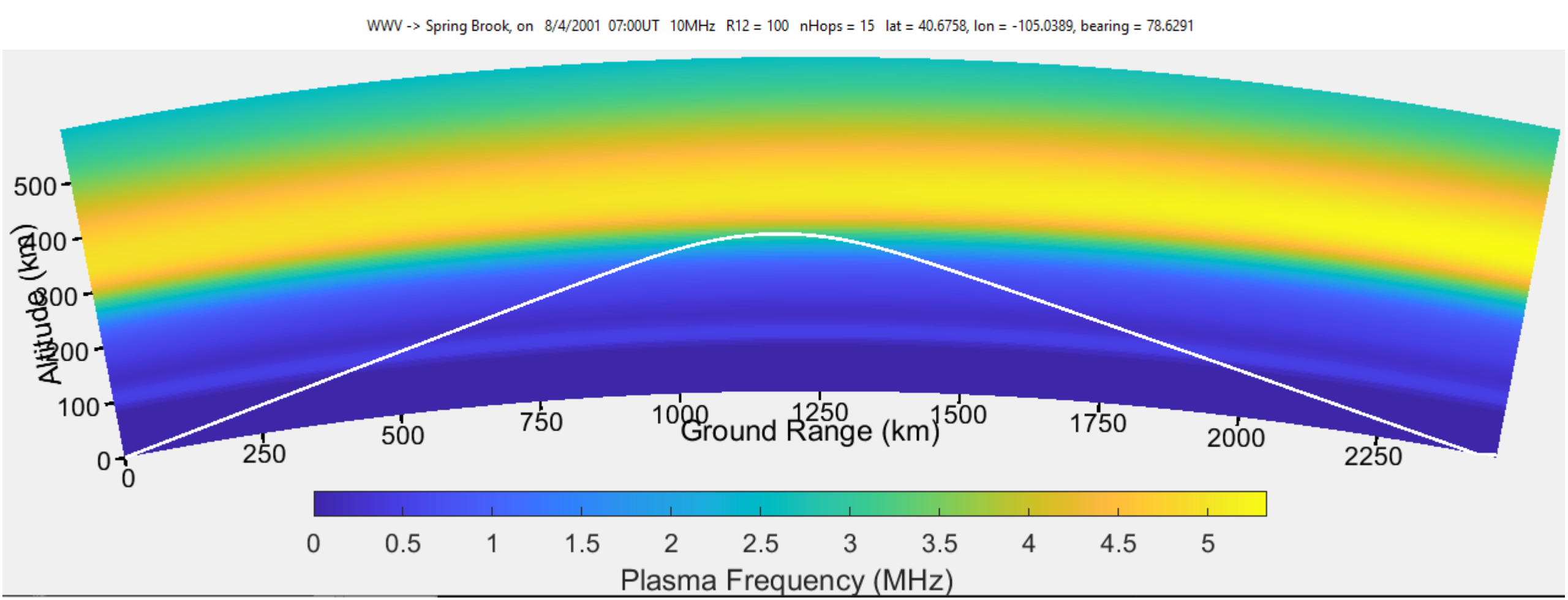
- Obtained via integrating the refractive index complex components along the ray path [26]
- Zawdie et al. (2017), used the complex refractive index formula with no magnetic field -> they require specifying the *effective collision frequency* in the collision frequency grid.

[26] Pederick and Cervera (2014), Radio Sci., 49, 81-93, doi:10.1002/2013RS005274
[27] Zawdie et al. (2017), Radio Sci., 52, 767-783, doi:10.1002/2017RS006256.

Same environment @10 MHz

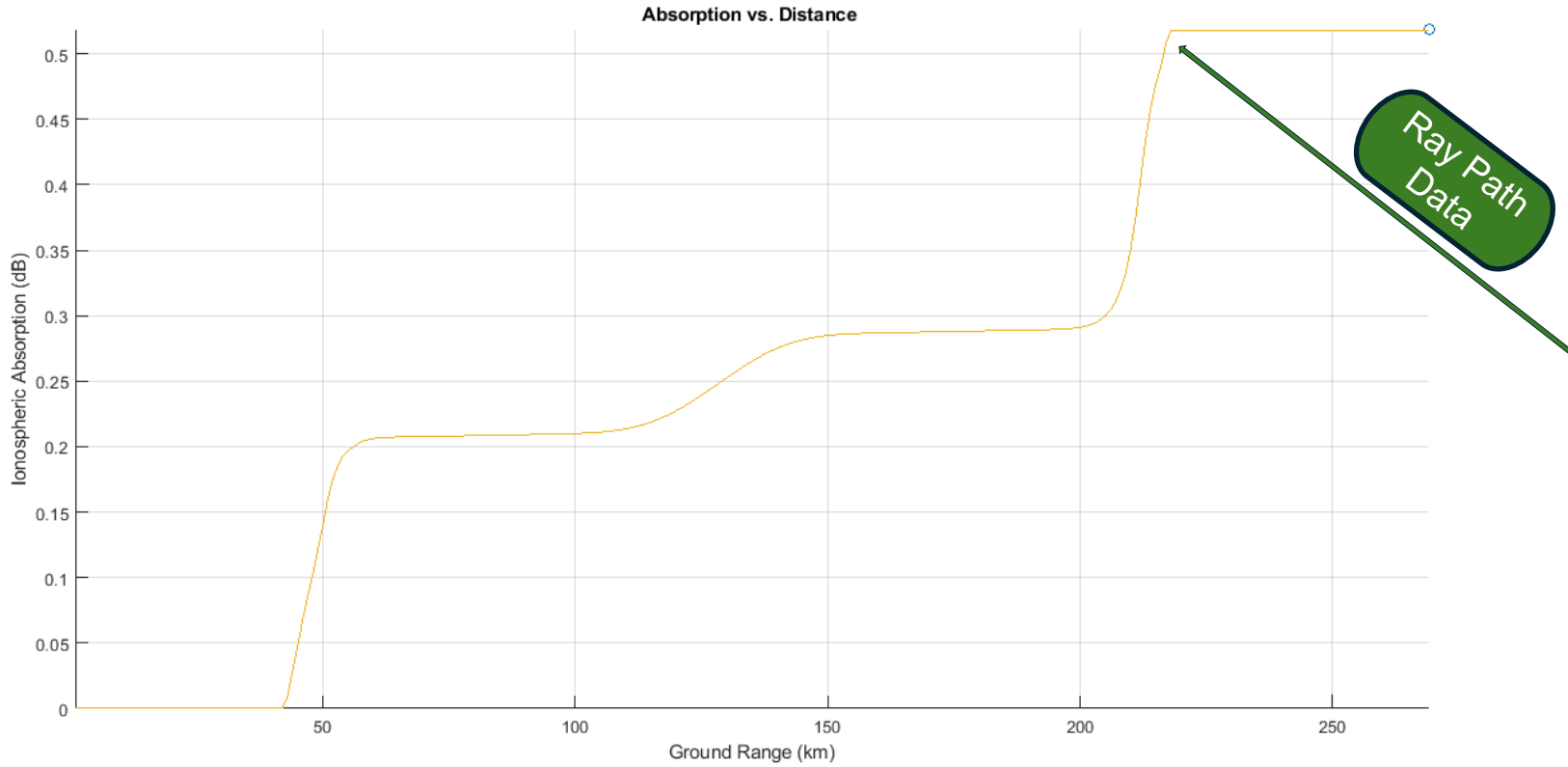


Picking the 10 degree-elevation ray



Ray Data again: (A First fraud x-axis !)

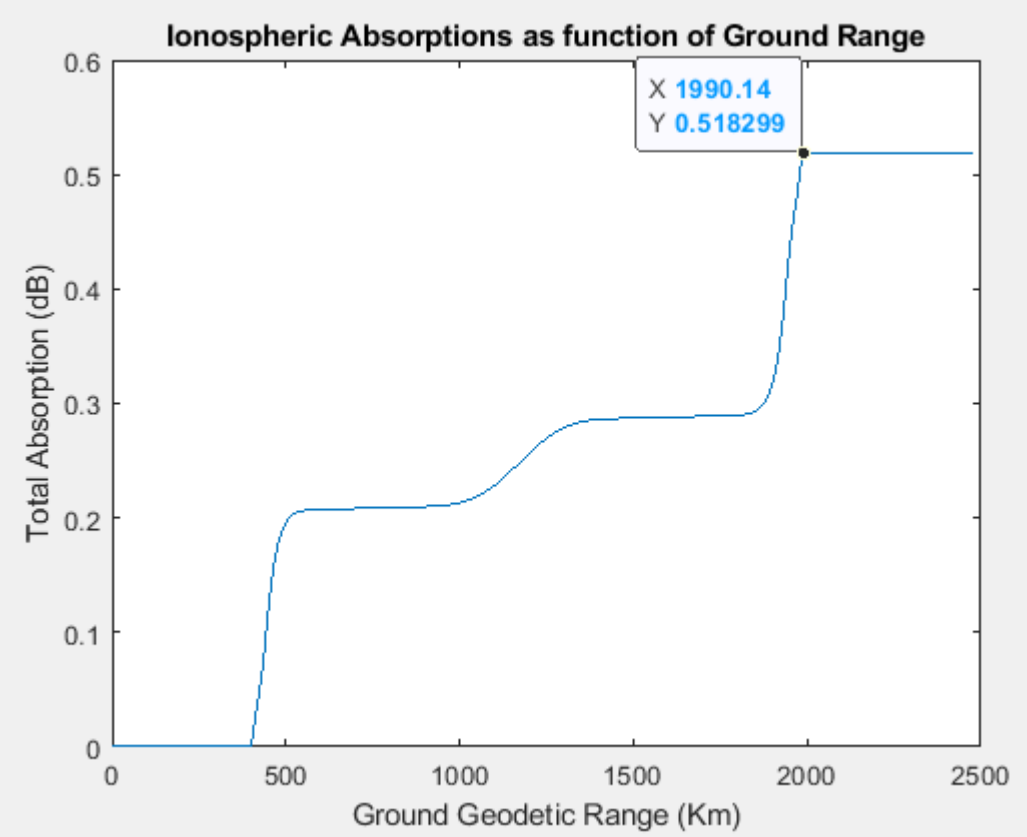
- Can we consider x-axis as the ground range?



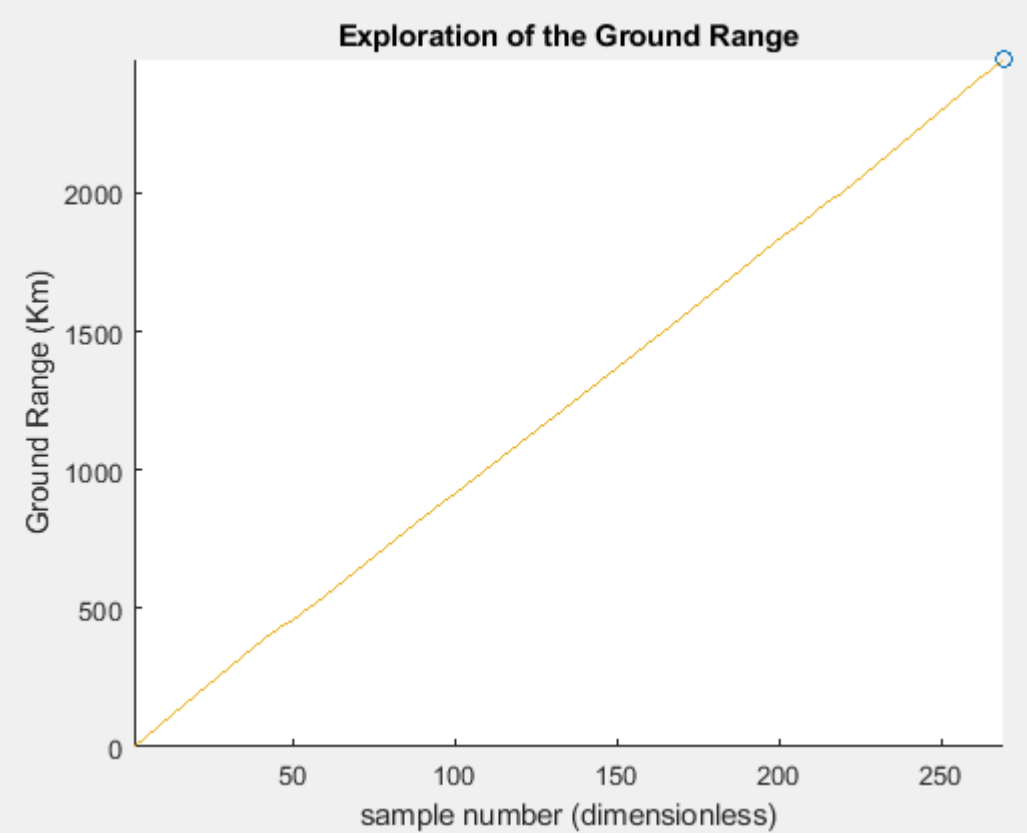
Ray Path Data

Field	Value
lat	[41.3687,41.3063]
lon	[283.9791,284.5632]
ground_range	[2.4304e+03,2.4798e+03]
group_range	[2.5710e+03,2.6210e+03]
phase_path	[2.5303e+03,2.5803e+03]
geometric_path_length	[2.5503e+03,2.6003e+03]
initial_elev	[10,8.6621]
final_elev	[8.6621,NaN]
apogee	[281.2918,NaN]
gnd_rng_to_apogee	[1.1780e+03,NaN]
plasma_freq_at_apogee	[3.2757,NaN]
virtual_height	[324.4013,NaN]
effective_range	[1.6080e+06,NaN]
total_absorption	[0.5183,0.5183]
deviative_absorption	[0.0846,0.0846]
TEC_path	[4.8643e+16,4.8643e+16]
Doppler_shift	[-0.0223,NaN]
Doppler_spread	[0,NaN]
FAI_backscatter_coeff	[NaN,NaN]
FAI_altitude	[NaN,NaN]
FAI_range	[NaN,NaN]
FAI_group_range	[NaN,NaN]
FAI_latitude	[NaN,NaN]
FAI_longitude	[NaN,NaN]
frequency	10
nhops_attempted	2
ray_label	[1,-3]
NRT_elapsed_time	0.0050

Exploring the Ground Range Variable



Manually Plot



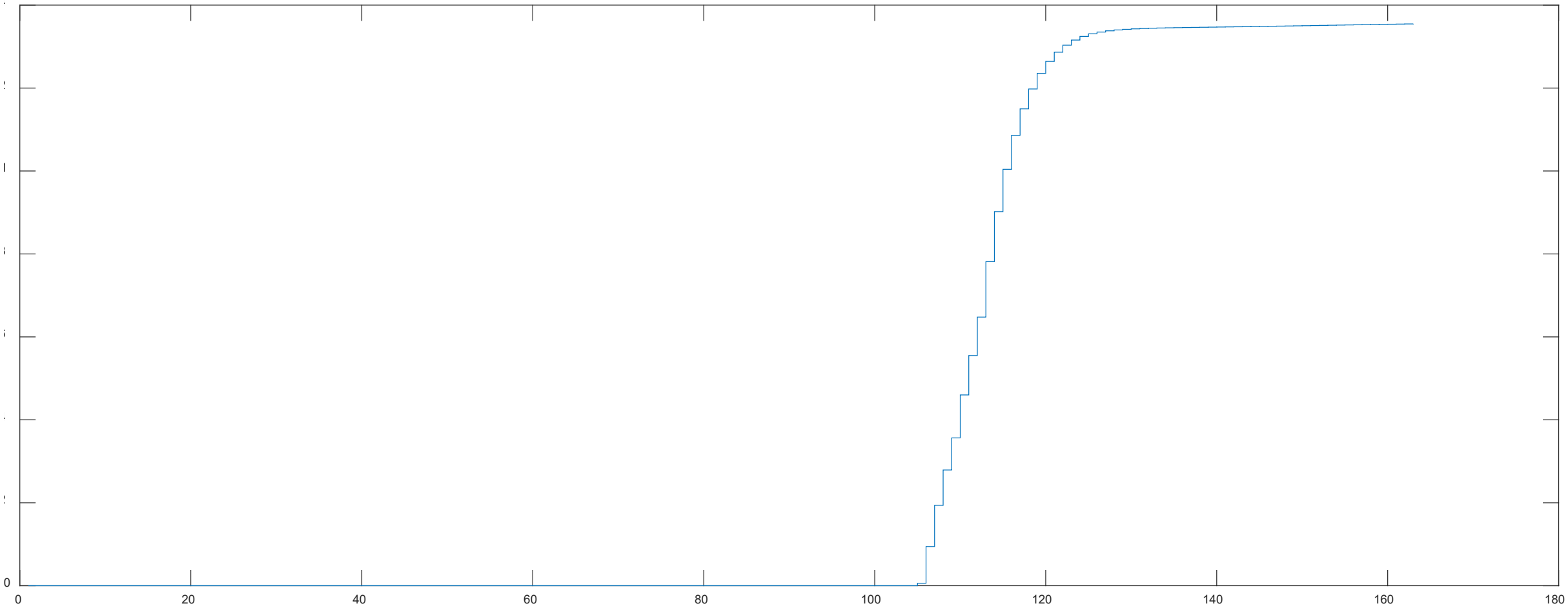
Total Absorption!

- Supposed ~100 dBs, [Dr. David McGaw]

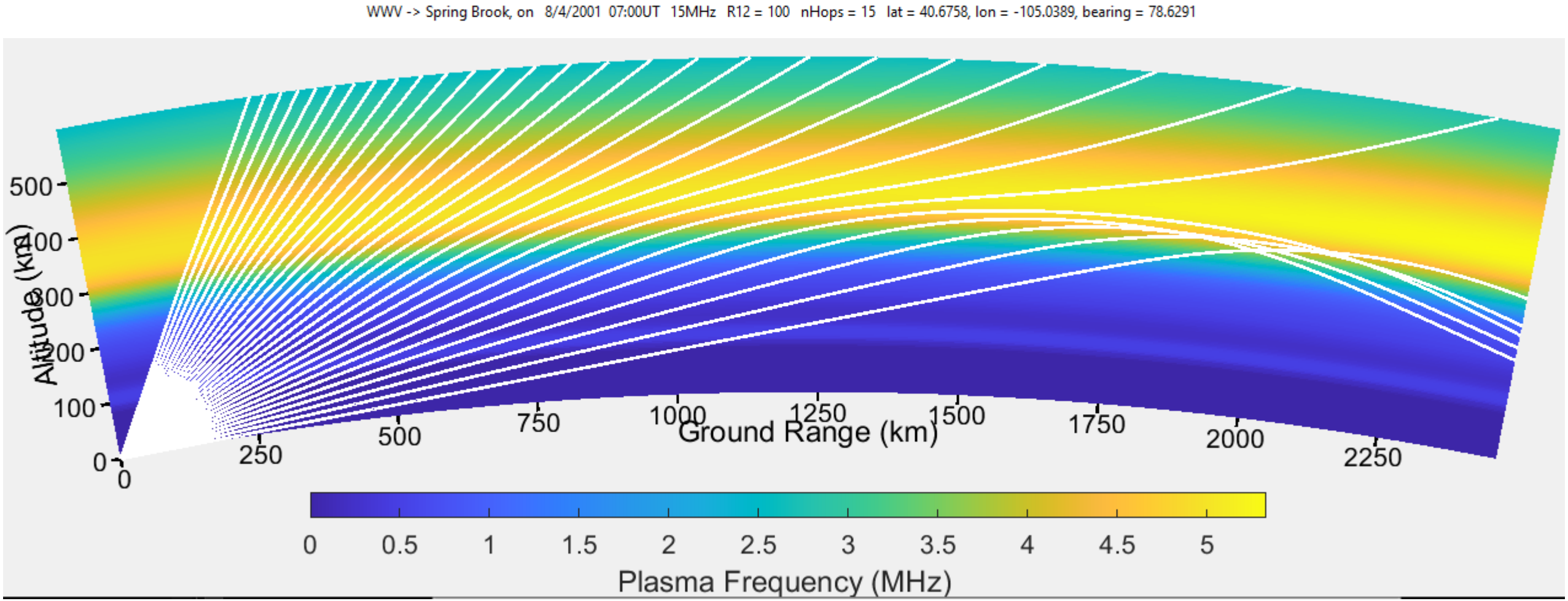
```
%     .theta                - Angle subtended by ray at the centre of the Earth
%                             (radians)
%     .delta_r              - delta_r (km) (see eqn 7 of Coleman RS, 33, pp1188)
%                             Required to calculate focussing gain/loss
%     .delta_Q              - delta_Q (see eqn 8 of Coleman RS, 33, pp1188).
%                             Required to calulate focussing gain/loss
%     .deviative_absorption - Ionospheric deviative absorption  (dB)
%     .phase_path           - Phase path (km)
%     .group_path           - independant var for RKF ode solver
%     .group_step_size      - Group path step size (km) for  ode solver
%
```

total_absorption	deviative_absorption
0.1355	0.0018
0.1349	0.0045
0.1616	0.0402
0.2408	0.1318
0.3572	0.2579
0.4614	0.3728
0.5077	0.4254
0.4787	0.4035
0.4250	0.3565
0.3738	0.3095
0.3309	0.2729
0.2993	0.2444
0.2726	0.2214
0.2515	0.2031
0.2321	0.1875
0.2171	0.1743
0.2041	0.1636
0.1920	0.1539
0.1816	0.1455
0.1738	0.1382
0.1654	0.1315
0.1589	0.1262
0.1524	0.1212
0.1473	0.1165

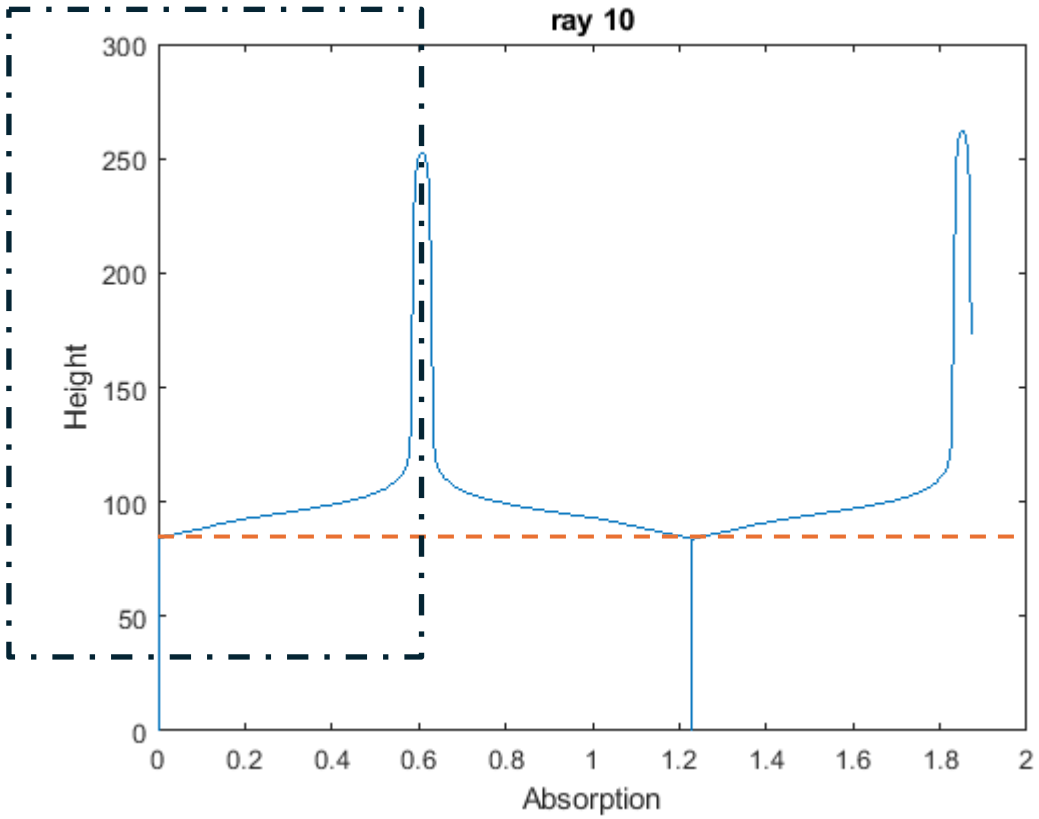
Total Absorption vs. ground points

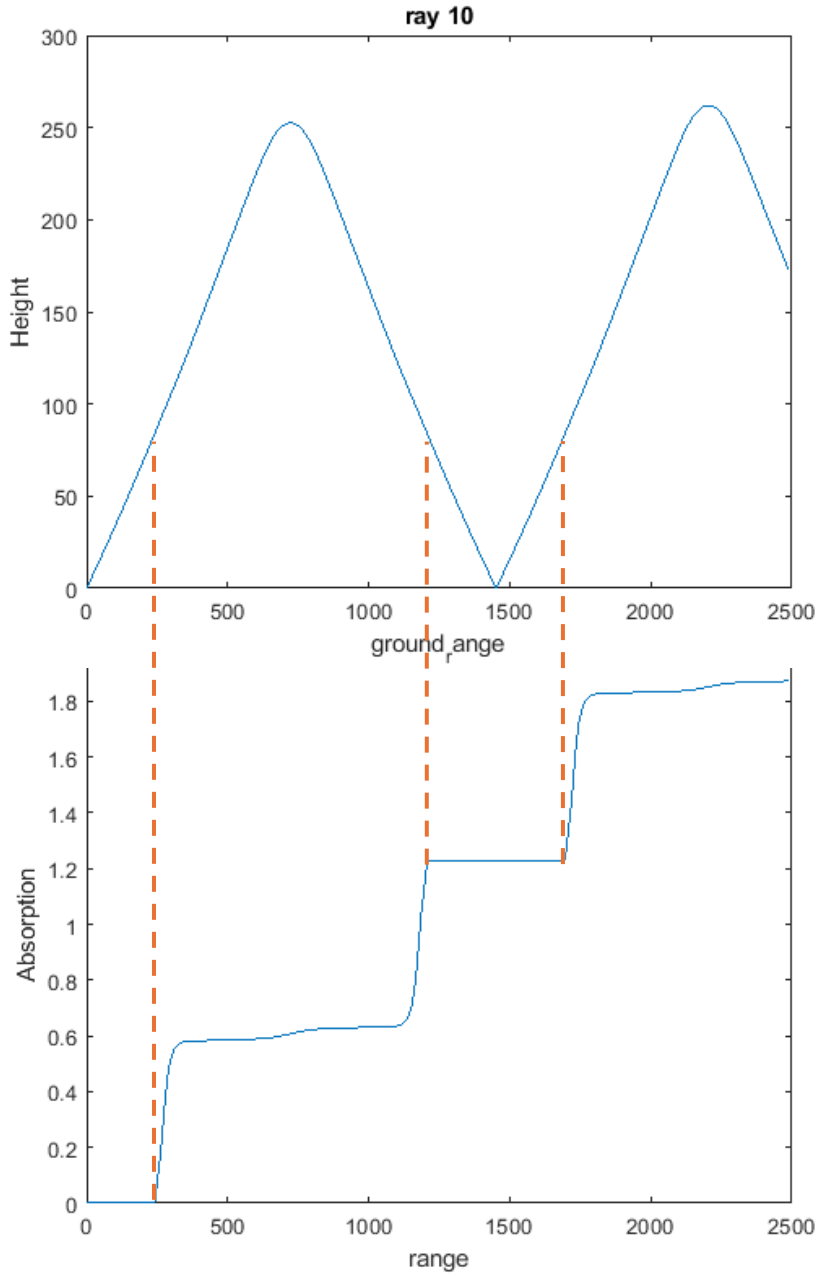


Same environment @15MHz: No reception!

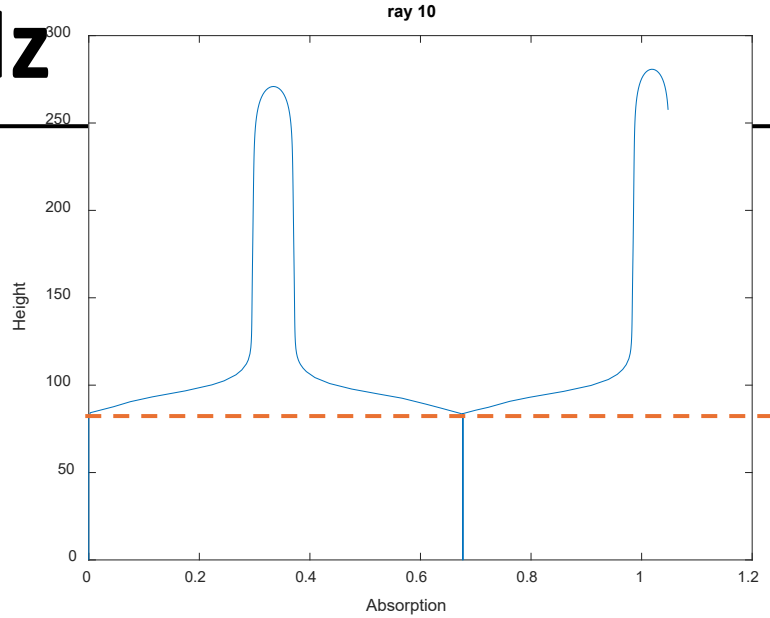


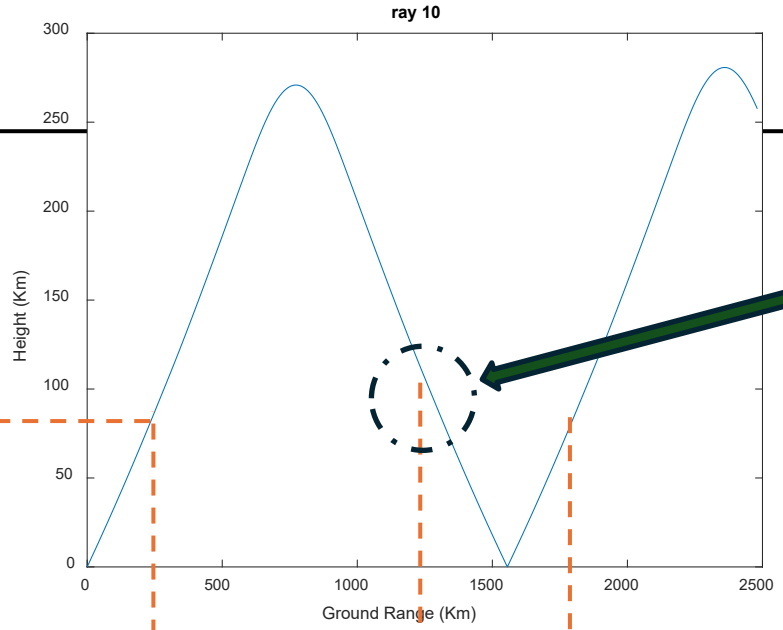
10th ray @5 MHz, WWV->W2NAF, max 5 hops

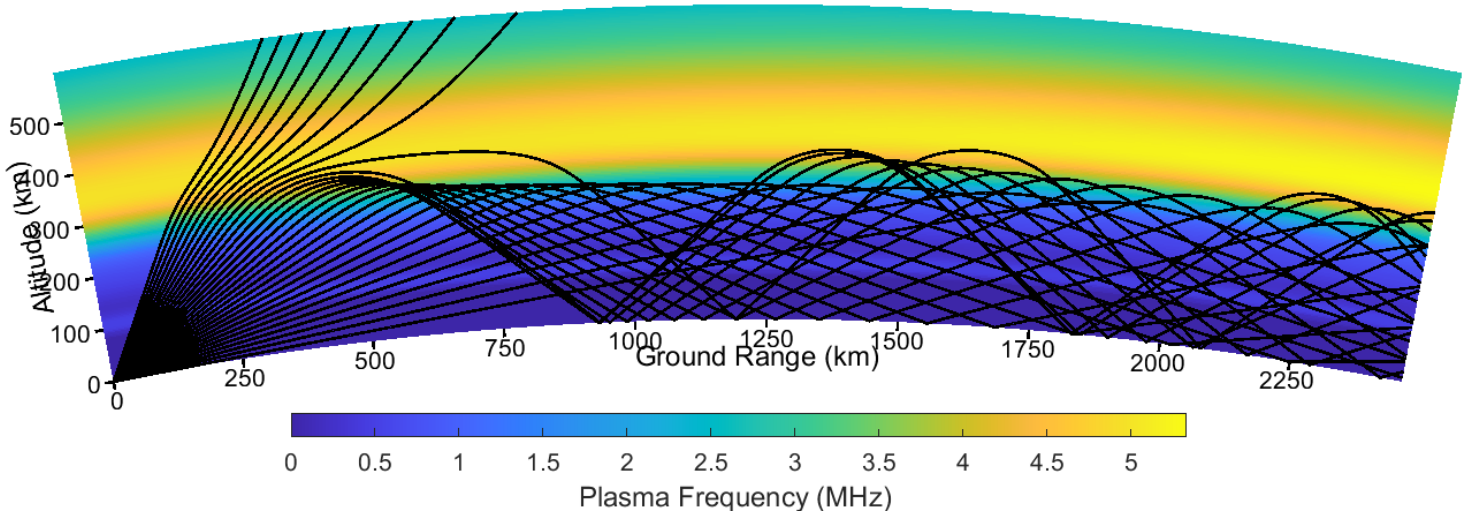


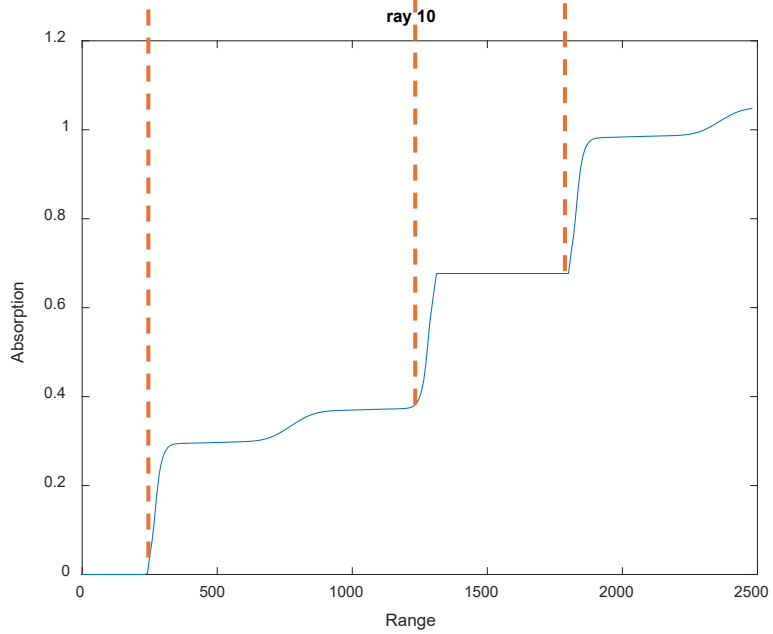


Same @7 MHz

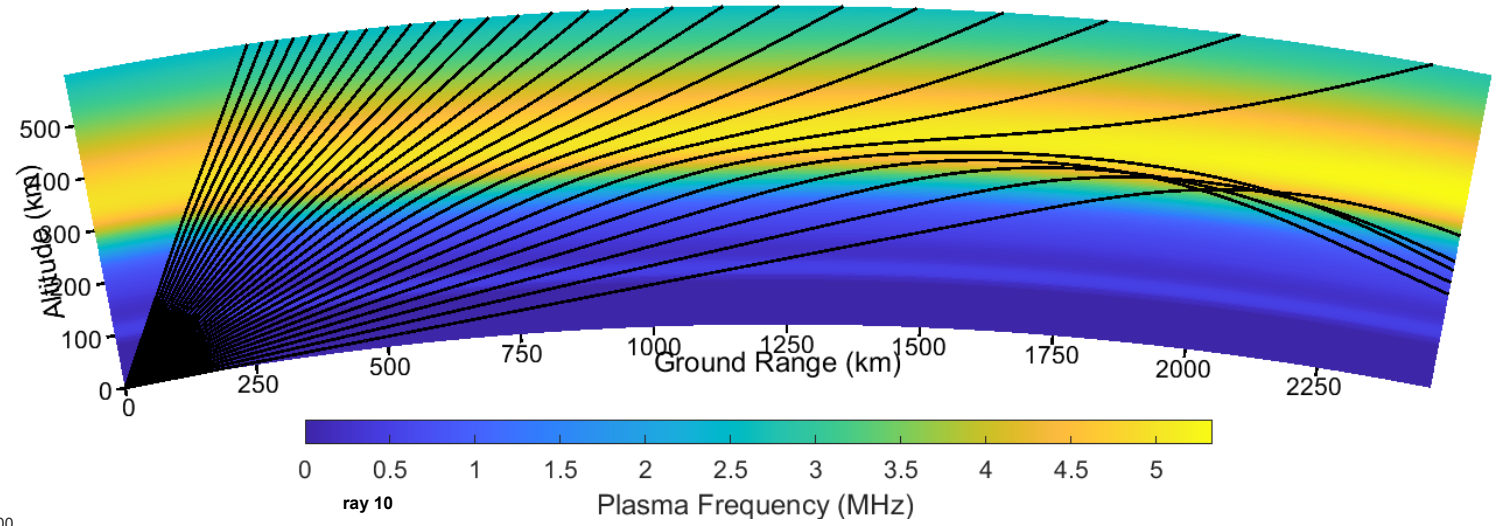

ray 10
Height
Absorption

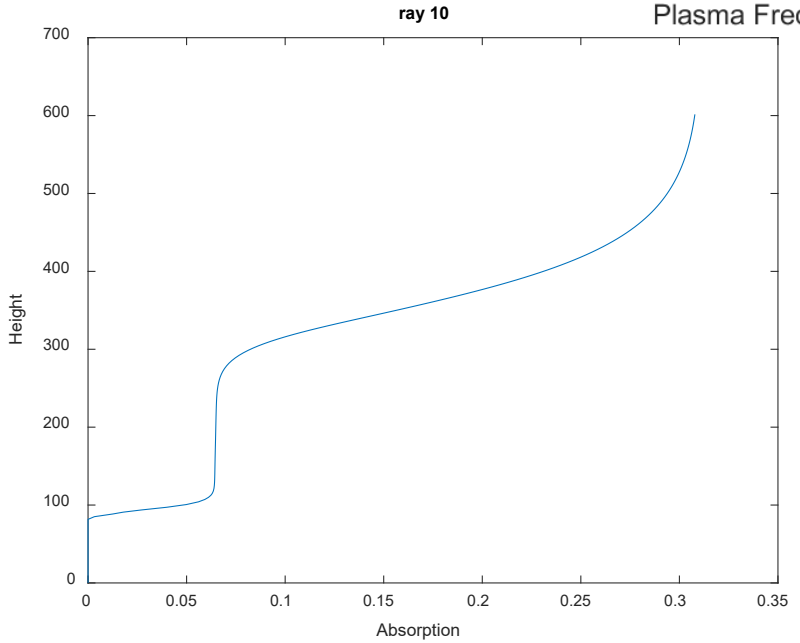

ray 10
Height (Km)
Ground Range (Km)

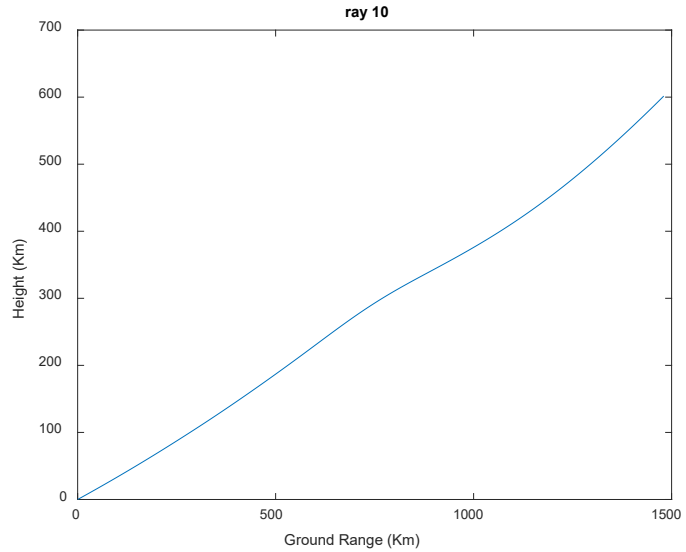

Altitude (km)
Ground Range (km)
Plasma Frequency (MHz)

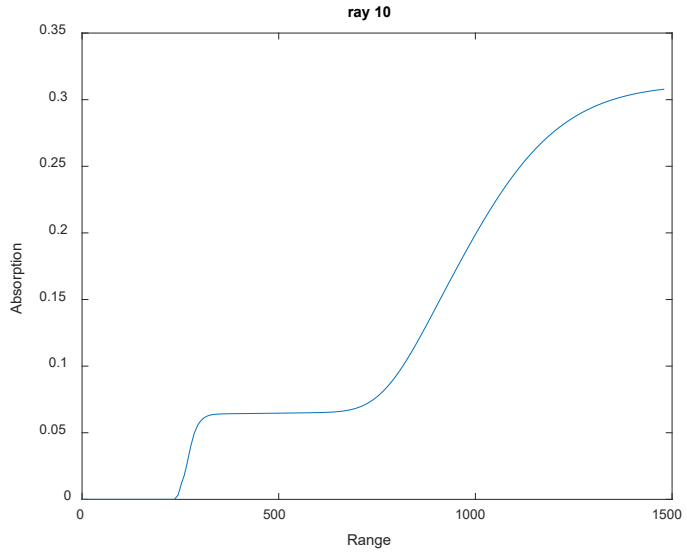

ray 10
Absorption
Range

Same@15 MHz

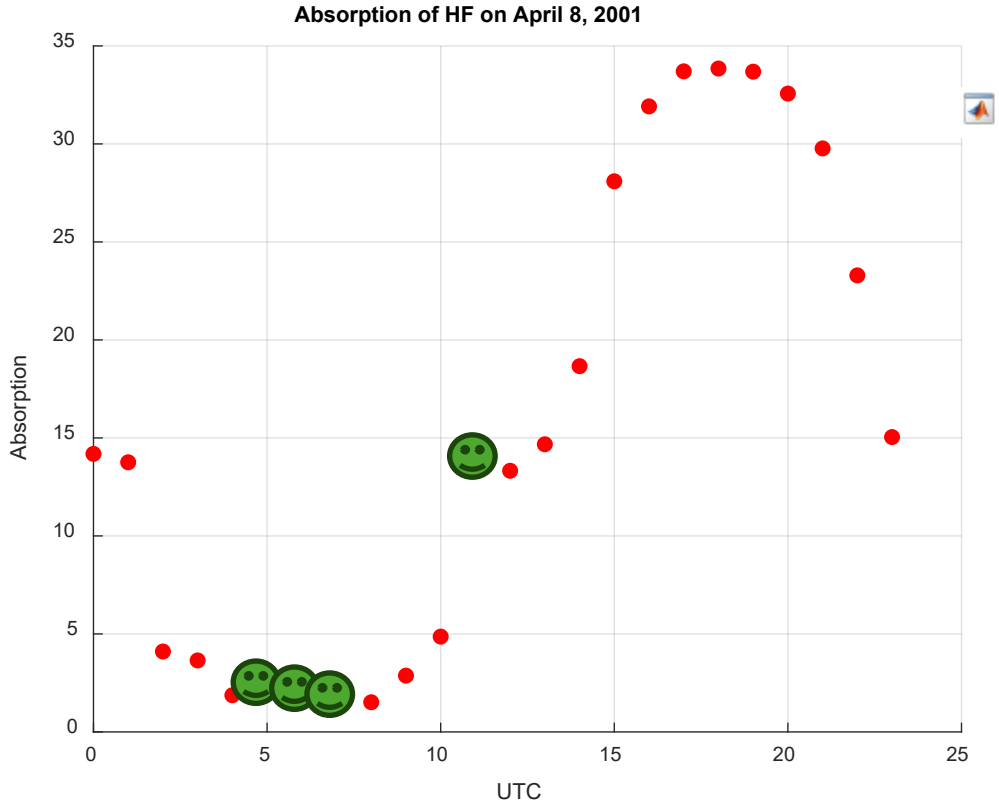

Altitude (km)
Ground Range (km)
Plasma Frequency (MHz)


ray 10
Height
Absorption


ray 10
Height (Km)
Ground Range (Km)


ray 10
Absorption
Range

```
73 de HamSCIHamSCI: Searching for the nearest front ray ...
Sorry, the hour 23 0 does not have a successful ray
 However, we reached the nearest worst-case ray#1 degrees at elevation of 0 degrees. Arriving 116.986880 kms away from W2NAF
```



Total Absorption vs UTC @5 MHz

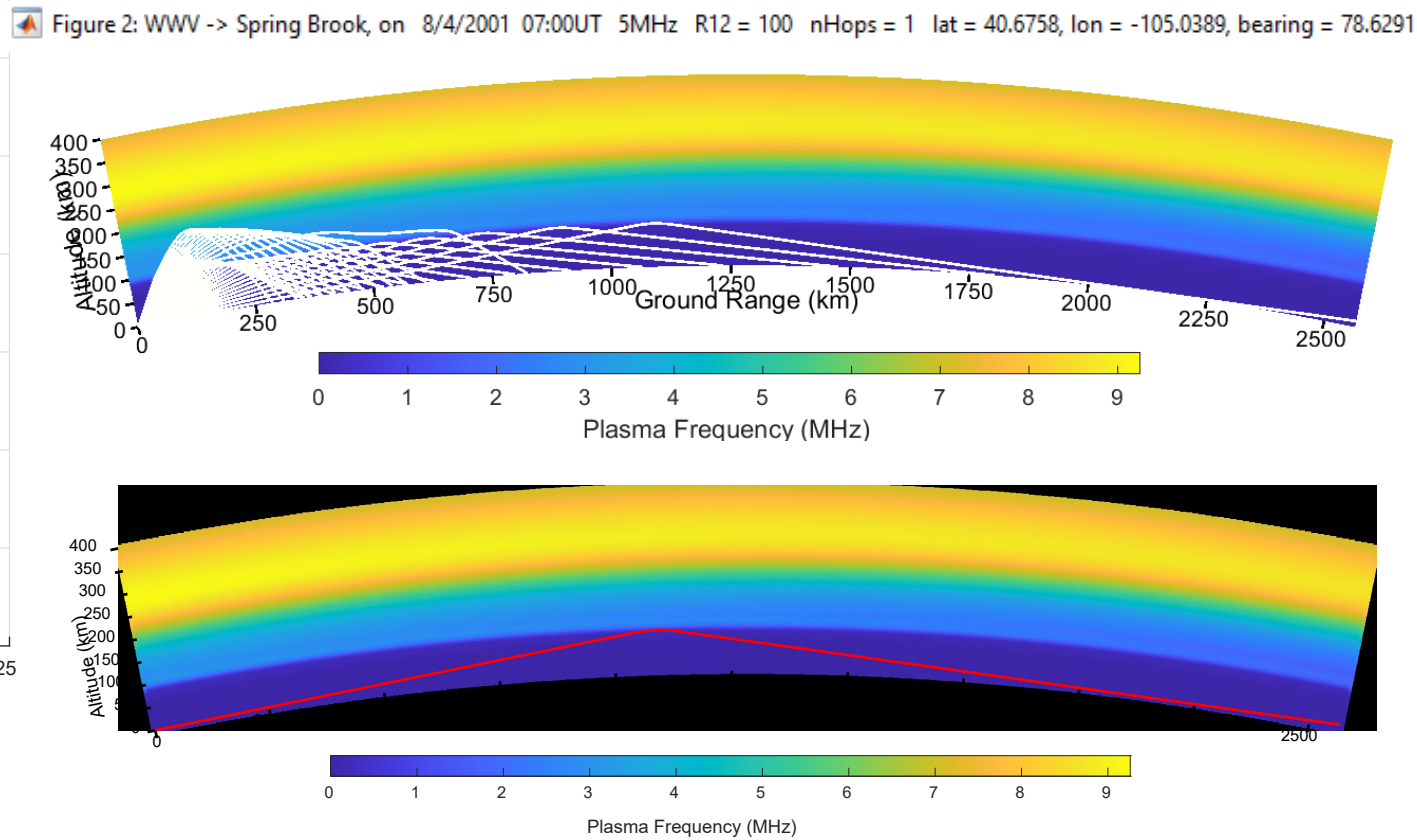
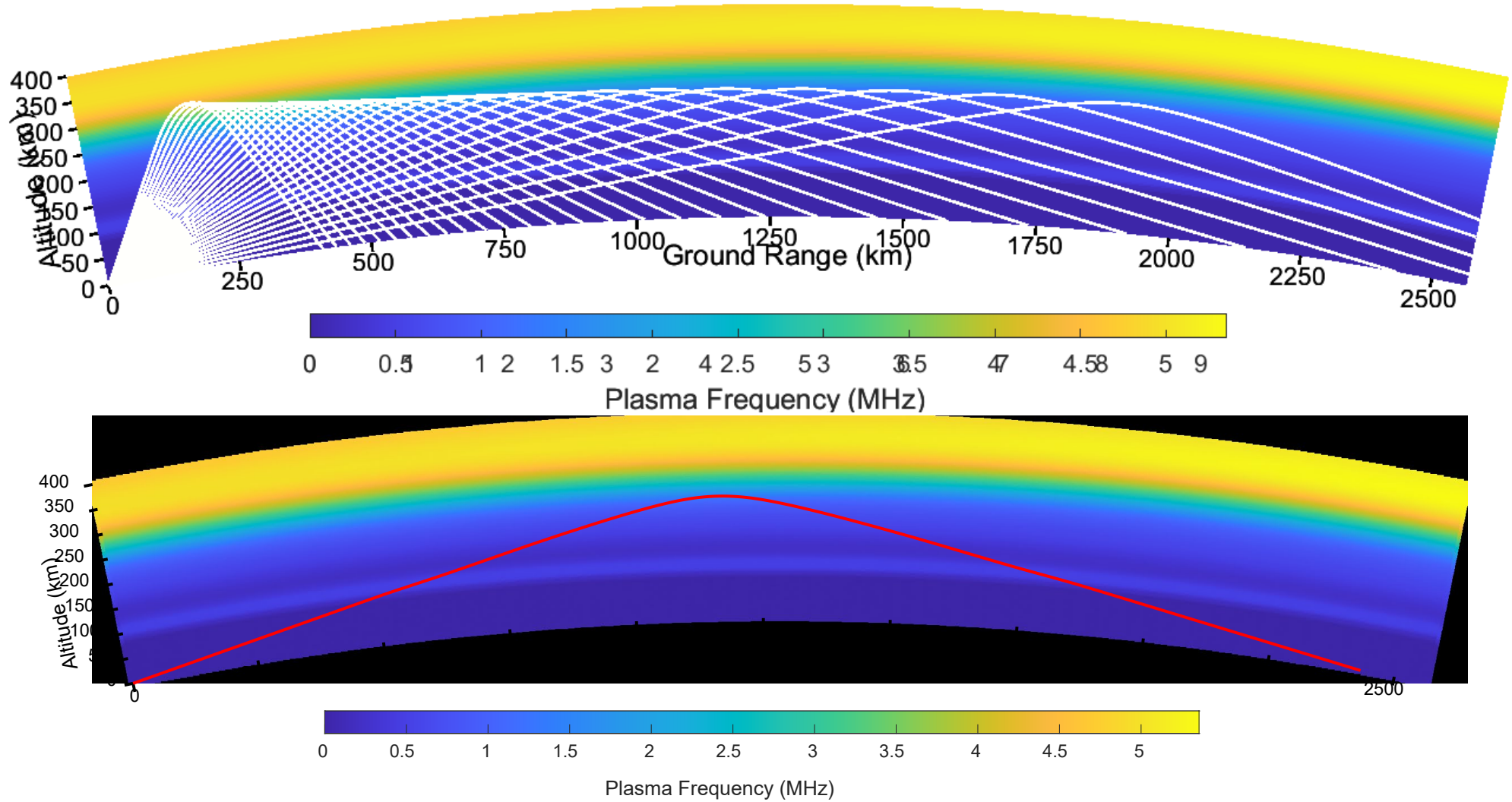


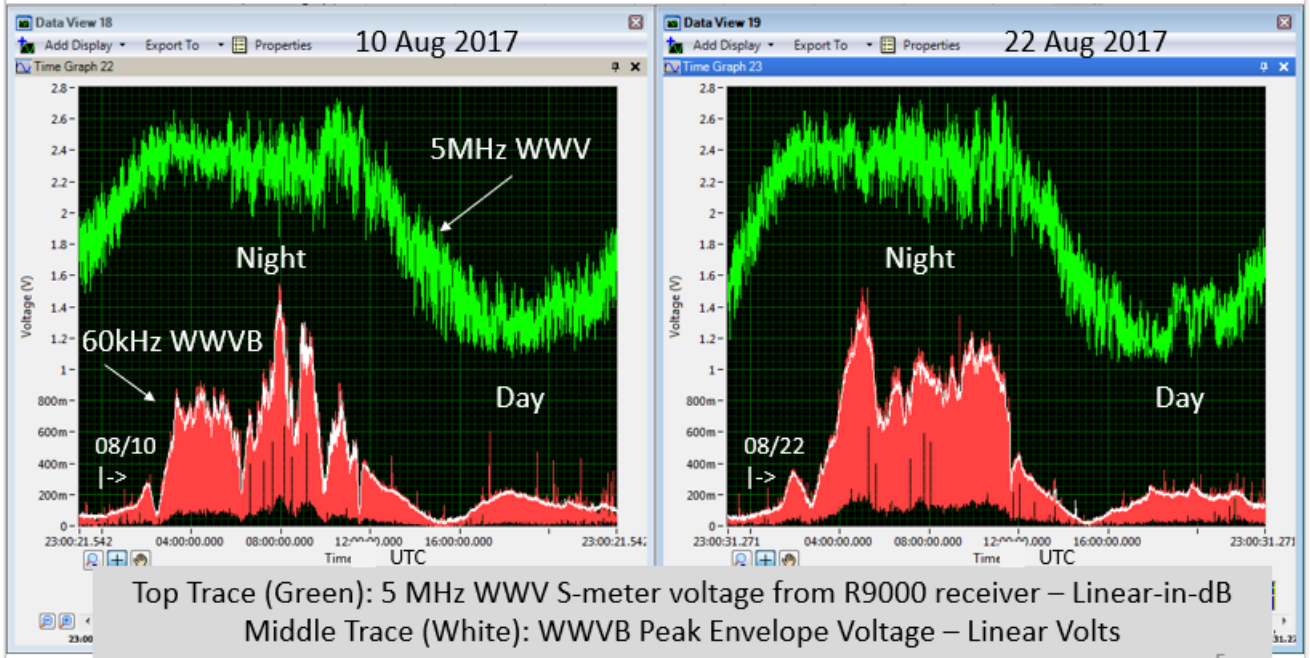
Figure 1: WWV -> Spring Brook 8/4/2001 07:00UT 5MHz R12 = 100 nHops = 1 lat = 40.6758, lon = -105.0389, bearing = 78.6291



Real WWV -> San Antonio

- [Steve Cerwin, 2027 Solar Eclipse Data]

24 Hour Recordings of WWVB and 5 MHz WWV
Before and After the Day of the 2017 Eclipse.
WWV and WWVB to WA5FRF.
Ft. Collins, CO to San Antonio, TX Path. 23-23 UTC.



Top Trace (Green): 5 MHz WWV S-meter voltage from R9000 receiver – Linear-in-dB
Middle Trace (White): WWVB Peak Envelope Voltage – Linear Volts
Bottom Trace: (Red): WWVB Demodulated Envelope Voltage – Linear Volts

5

Future Work

- We aspire to model the absorption loss due to ground reflections:
  - Reflection Coefficient maps covering U.S.
  - Getting more into Brewster's angle involvement.
- We aspire to figure out a model for D-Region:
  - SAMI3 model does cover the D-Region!
  - Modeling the D-Region during eclipse (neither PHaRLAP nor SAMI3)

References

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A Good Learner is a Good Developer!

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HamSCI silhouette photo by Ann Marie Rogalcheck-Frissell KC2KRQ.

Thank you! Any Questions?