3.5 GHz Propagation Measurements

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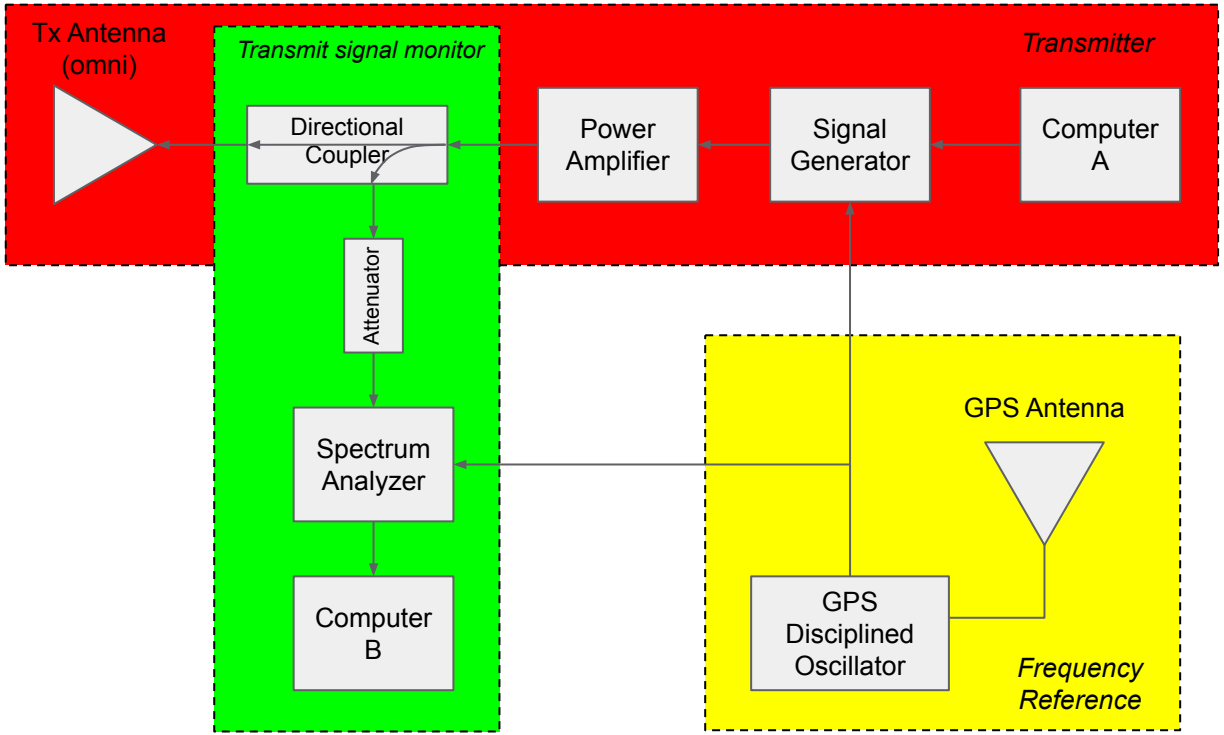
Summary

- Propagation measurements have been conducted at 3.5 GHz to quantize the impact of clutter, where “clutter” refers to buildings and foliage along the propagation path
- To date, approximately 1.7E6 measurements have been made in two separate geographic areas:
  - The majority of measurements have been made in a heavily cluttered environment on the east coast
  - Additional measurements have been made in a light-to-moderate clutter environment on the west coast
- The initial goals of the project are to:
  - Compare the measurement results with those predicted by commonly-used propagation models
  - Examine the effects of buildings and of foliage along the propagation path
  - Examine the effects of height relative to the surrounding clutter

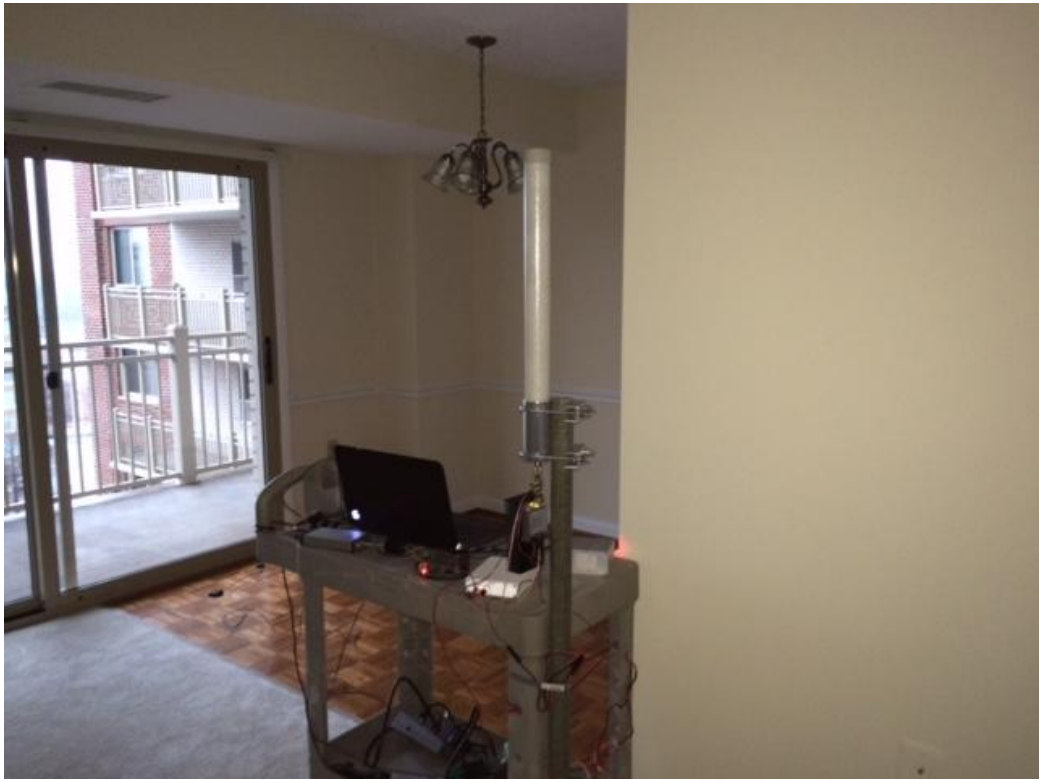
Transmitter Hardware Configuration

CW tone
+44 dBm EIRP
3557 MHz +/- 1 Hz



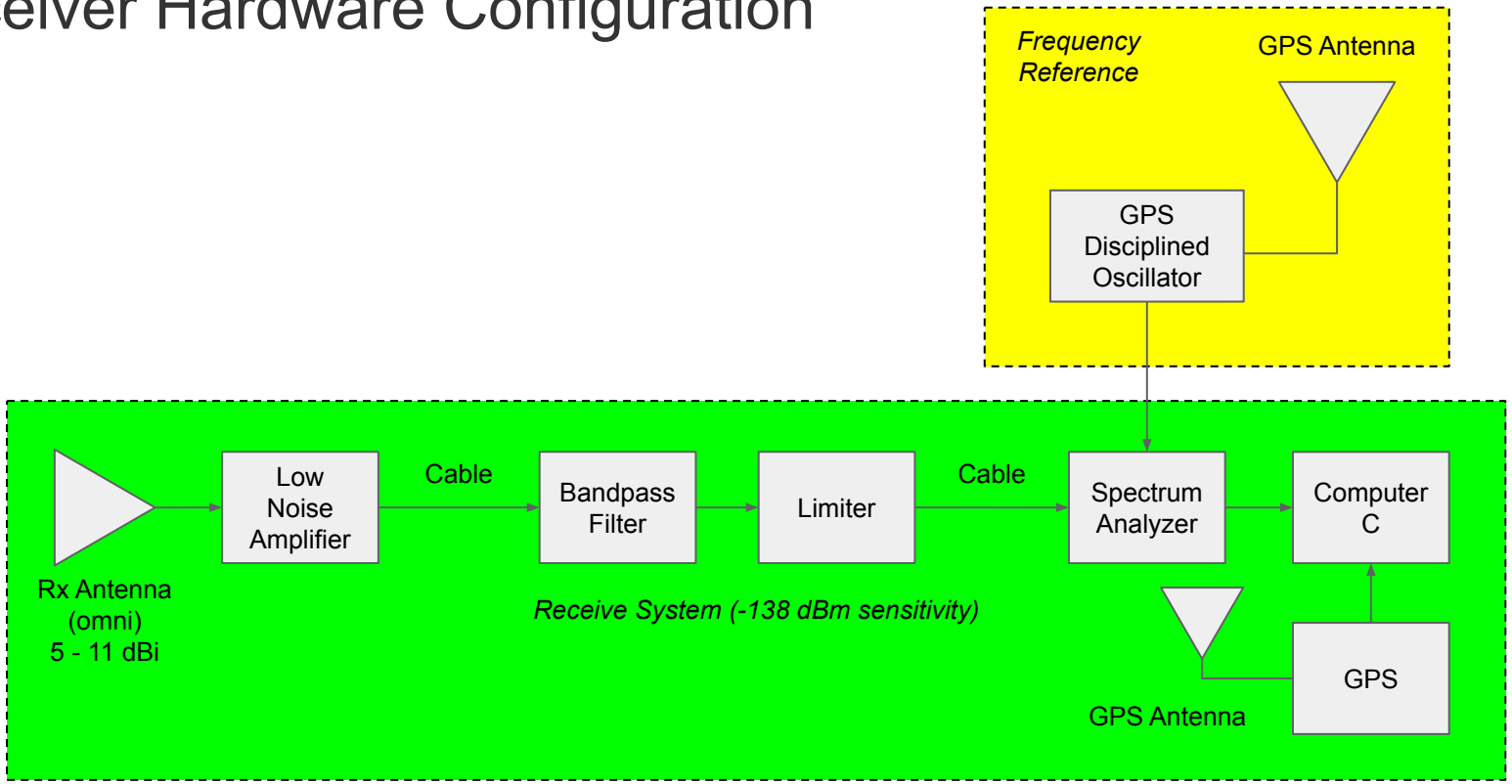
Transmitter (Typical Outdoor Configuration)

Transmitter (Typical Indoor Configuration)



Transmitter (Rooftop Configuration)

Receiver Hardware Configuration



Vehicle-Mounted Receiver System

Propagation Loss Measurement Range

- Tx power: +44 dBm EIRP
- Rx sensitivity: -142 dBm (w/ 11 dBi rx antenna)
- Maximum measurable propagation loss: ~186 dB
  - Equivalent to 13,400 km of free space loss, no clutter
  - Equivalent to ~75 km trans-horizon over-ocean LR loss (diffraction region)
  - Equivalent to ~few km in clutter

Primary Measurement Environment

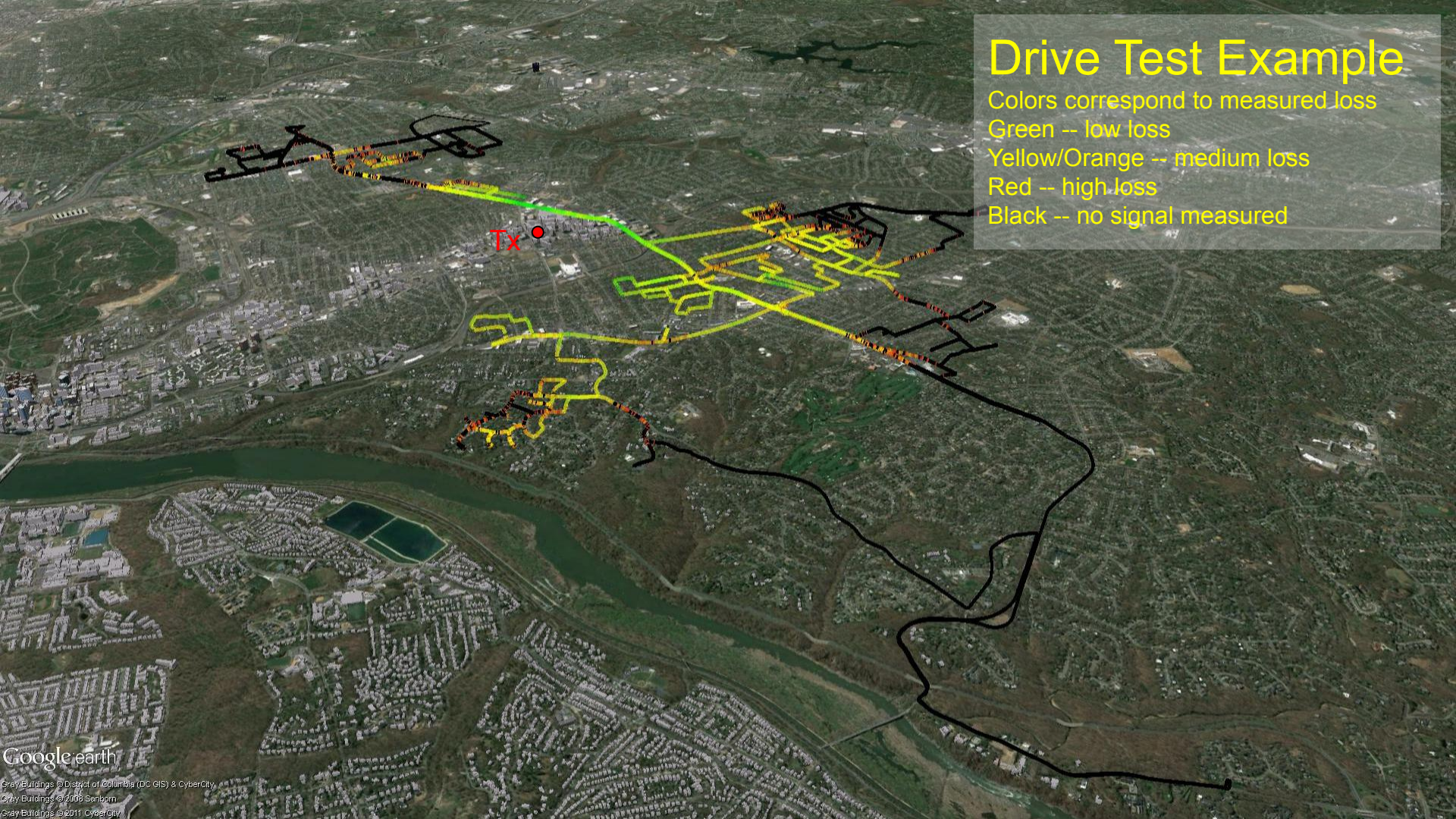
- Arlington, Virginia
- Core test area is within the urban Metro corridor, surrounded by dense suburban
- Transmitter installed outdoors and indoors, on various floors, in a high-rise apartment building that is one of the taller buildings in its area

Range of Tested Parameters

- Outdoor & indoor
- Summer and winter
- Dry/rain/snow
- Mobile/stationary
- Different tx heights above ground level
  - 2nd floor, 6.1 m
  - 6th floor, 17.4 m (outdoor only)
  - 12th floor, 33.1 m
  - 16th floor, 43.9 m
  - Rooftop (~23 floor), 63.4 m (outdoor only)

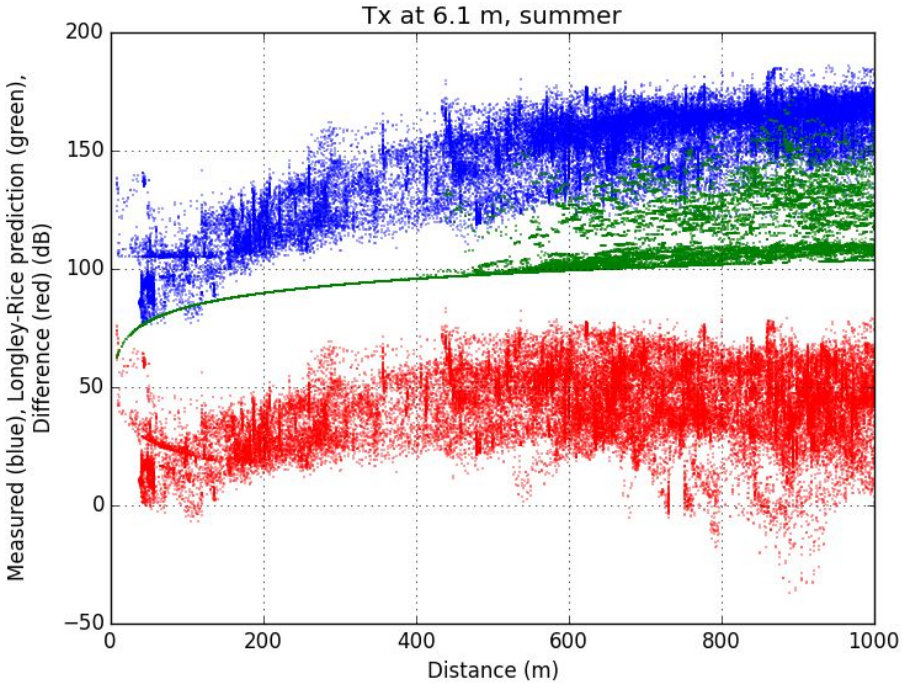
Transmitter Location

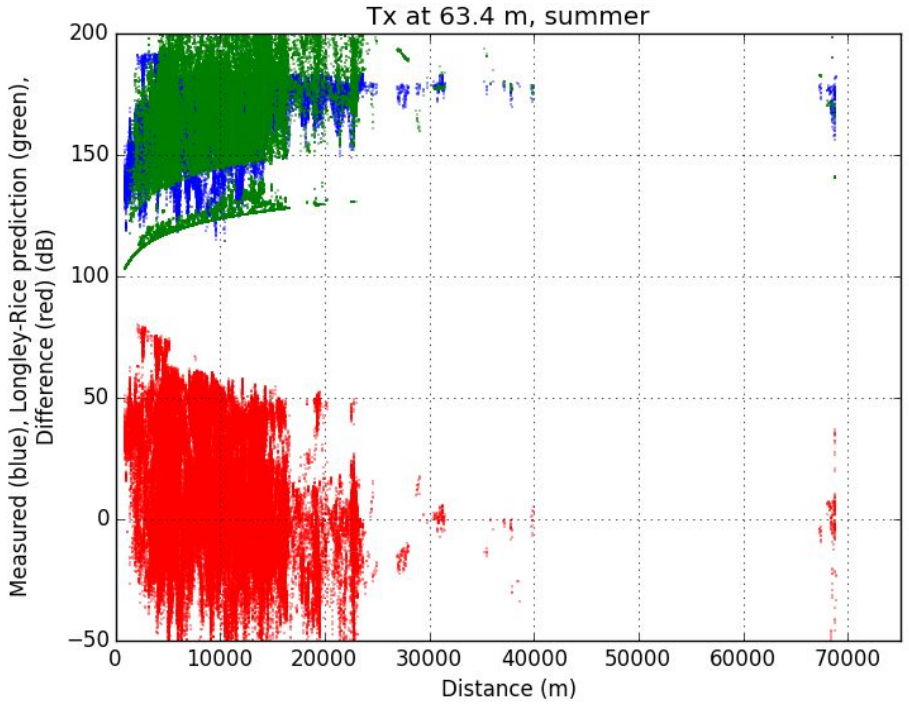
Transmitter Locations


Drive Test Example
Colors correspond to measured loss
Green -- low loss
Yellow/Orange -- medium loss
Red -- high loss
Black -- no signal measured
Tx
Google earth
Gray Buildings © District of Columbia (DC GIS) & CyberCity
Gray Buildings © 2008 Sanborn
Gray Buildings © 2011 CyberCity

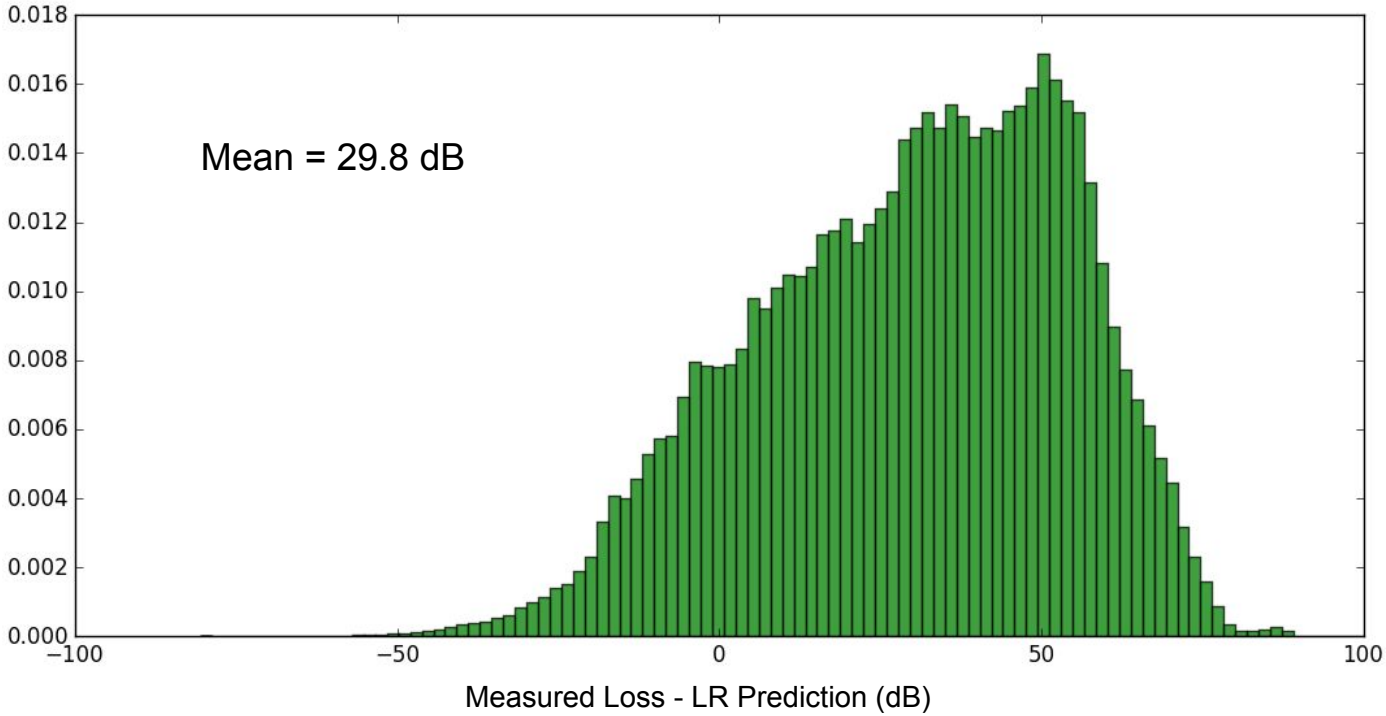
Google

Data Examples

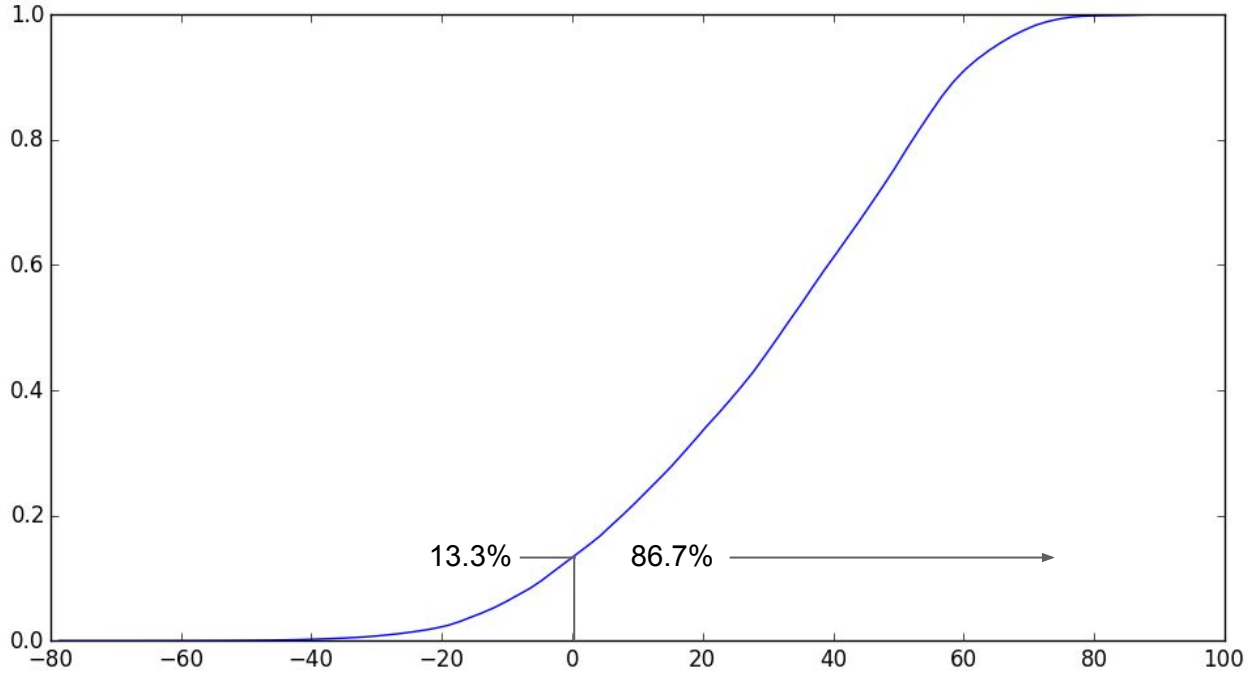




Probability Distribution Function (all measurements)



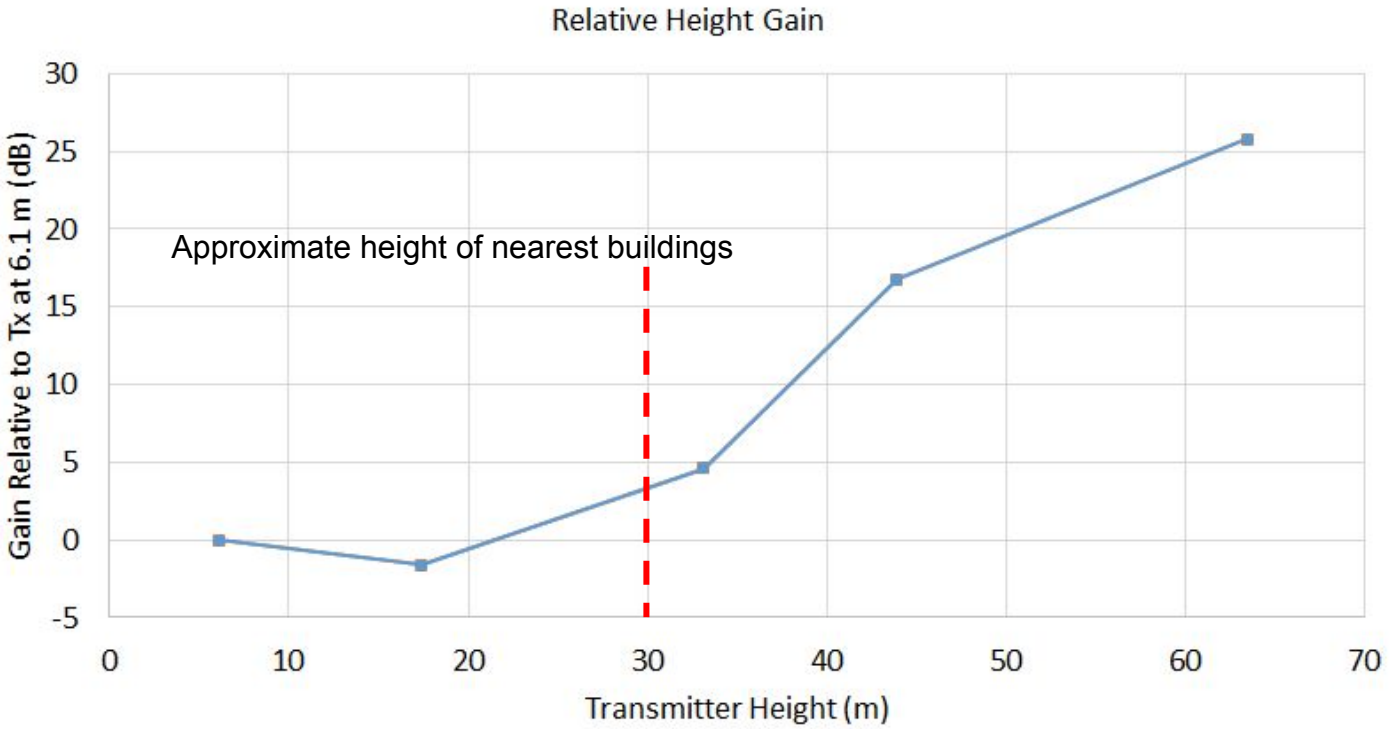
Cumulative Distribution Function (all measurements)



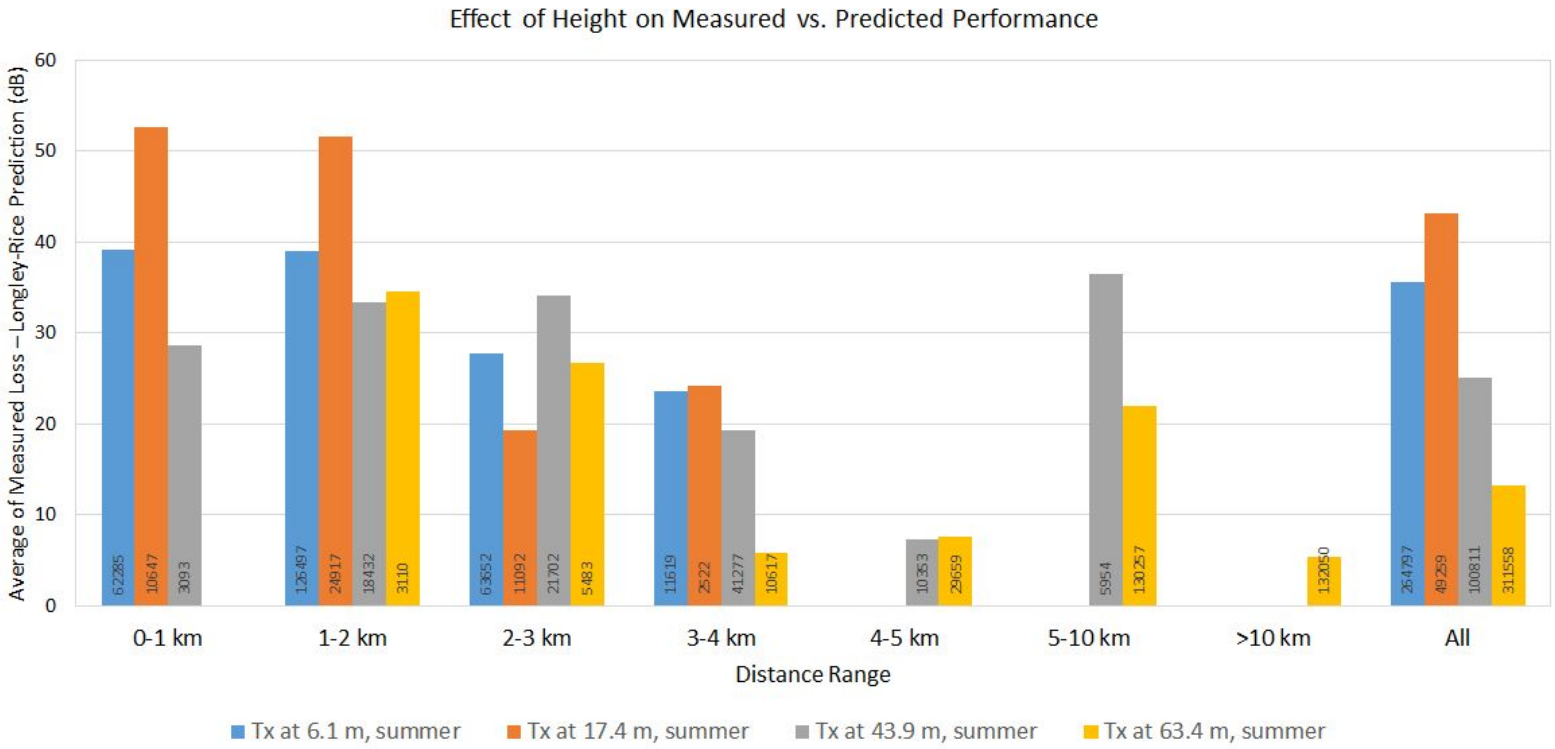
Data Comparison Methods

- Effects of height, location, weather, etc., are determined by comparing data obtained under different circumstances
- Two methods are used to compare data:
  - Bulk comparison
    - Given the statistically large number of data points, we can compare the average of all data obtained under different circumstances across all locations
  - Grid comparison
    - The data for particular circumstances are placed on a geographic grid, and data points within corresponding pixels of different grids are compared. This technique assures comparison of data points obtained at the same location

Relative Height Gain (by Grid Comparison)

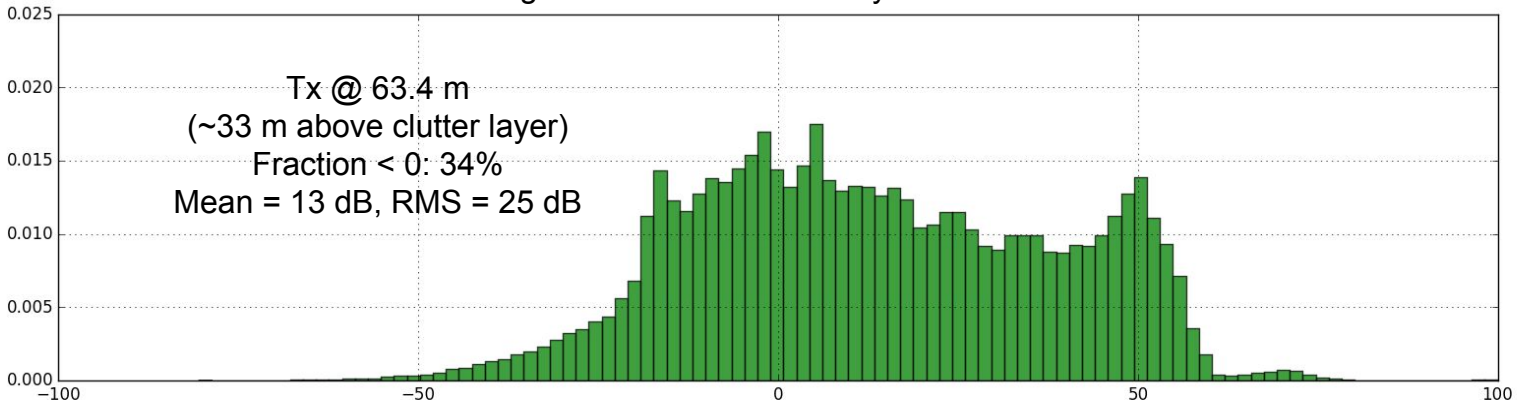


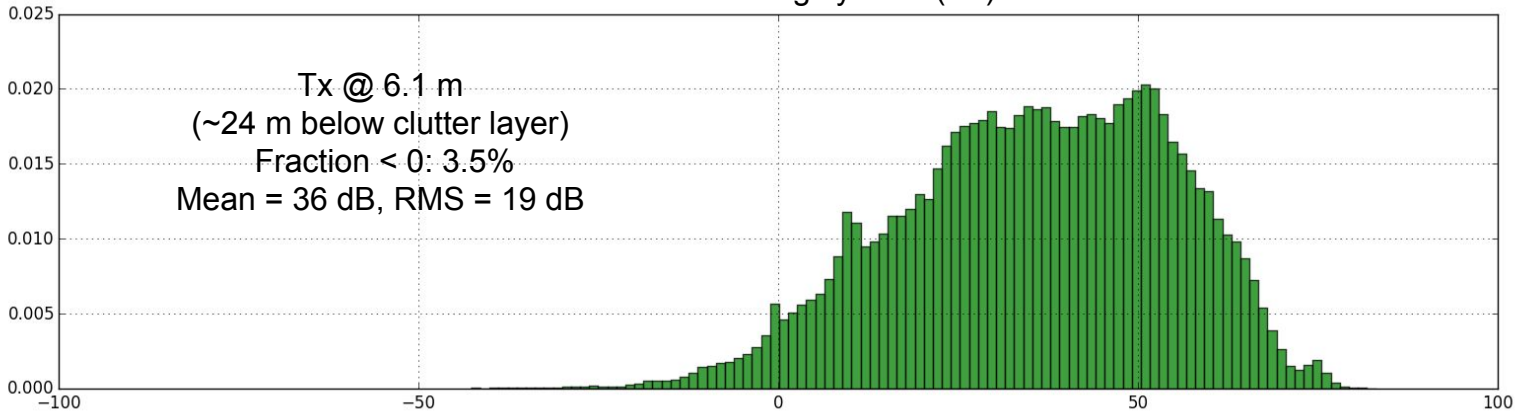
Longley-Rice Comparison vs Distance & Tx Height



Google

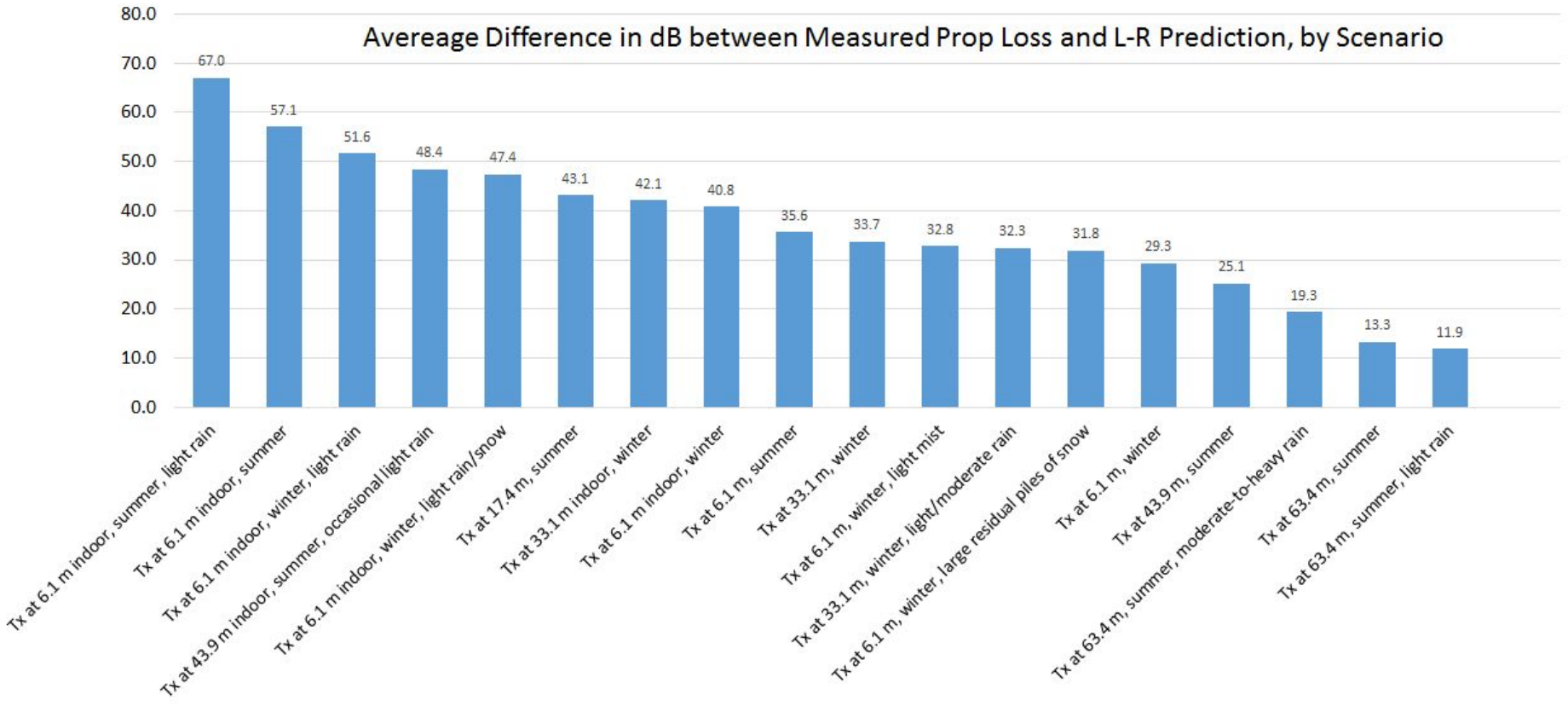
Effect of Height Relative to Clutter Layer on LR Prediction





Summer vs. Winter; Outdoor vs. Indoor; Precipitation

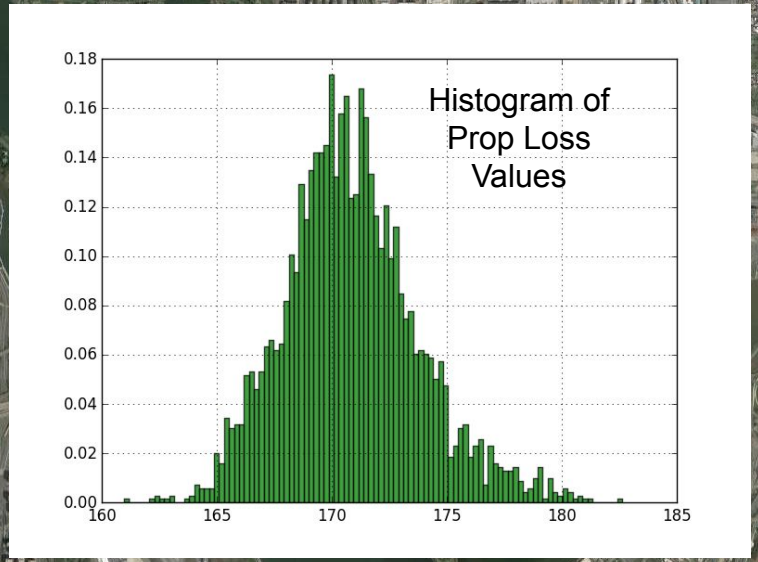
- Summer vs Winter
  - Based on 17,364 co-located grid points for tx at 6.1 m, the difference between summer and winter (leaves on vs. leaves off) is 6.0 dB (higher loss in summer)
- Outdoor vs. Indoor
  - Difference is 15.1 dB based on 2248 co-located grid points
- Precipitation
  - Outdoor @ 63.4 m, moderate-to-heavy rain: insignificant difference 0.9 dB (higher loss when dry) (270 co-located grid points)
  - Indoor @ 6.1m, heavy rain: difference 9.6 dB (higher loss when raining) (440 co-located grid points)
  - Outdoor @ 6.1 m, moderate snow: no discernible difference (<0.1 dB) (4066 co-located grid points)


Avereage Difference in dB between Measured Prop Loss and L-R Prediction, by Scenario
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
67.0
57.1
51.6
48.4
47.4
43.1
42.1
40.8
35.6
33.7
32.8
32.3
31.8
29.3
25.1
19.3
13.3
11.9
Tx at 6.1 m indoor, summer, light rain
Tx at 6.1 m indoor, summer
Tx at 6.1 m indoor, winter, light rain
Tx at 43.9 m indoor, summer, occasional light rain
Tx at 6.1 m indoor, winter, light rain/snow
Tx at 17.4 m, summer
Tx at 33.1 m indoor, winter
Tx at 6.1 m indoor, winter
Tx at 6.1 m, summer
Tx at 33.1 m, winter
Tx at 6.1 m, winter, light mist
Tx at 33.1 m, winter, light/moderate rain
Tx at 6.1 m, winter, large residual piles of snow
Tx at 6.1 m, winter
Tx at 43.9 m, summer
Tx at 63.4 m, summer, moderate-to-heavy rain
Tx at 63.4 m, summer
Tx at 63.4 m, summer, light rain

Example Stationary Measurements

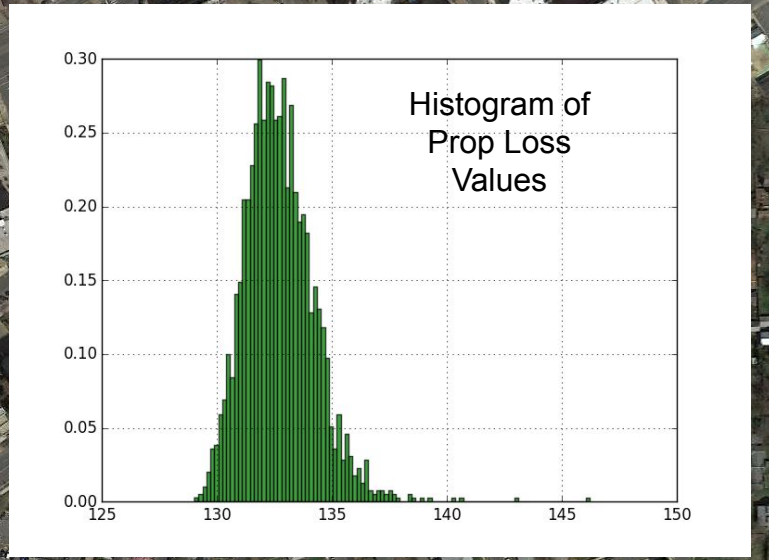
- Rx held stationary for ~10 - 60 min to test longer-term fading statistics

Tx & Rx Stationary
Tx height: 63.4 m
Rx height: 1.5 m
Pathlength: 8.0 km
Number of measurements: 3217
Measurement Time: ~50 minutes
Measured loss: 170.8 +/- 2.9 dB
L-R prediction: 121.5 dB
Difference: 49.3 dB

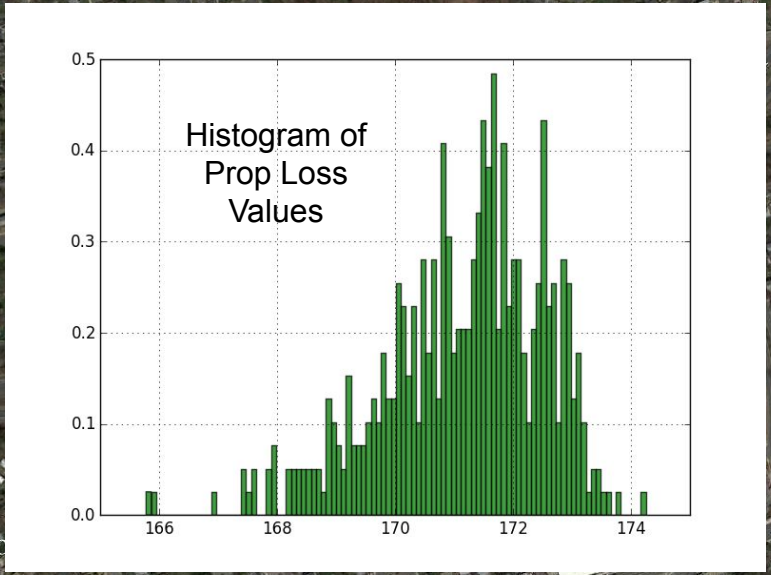


Tx & Rx Stationary
Light rain/snow
Tx height: 6.1 m (indoors)
Rx height: 1.5 m
Pathlength: 445 m
Number of measurements: 2273
Measurement Time: ~40 minutes
Measured loss: 132.7 +/- 1.5 dB
L-R prediction: 96.4 dB
Difference: 36.3 dB

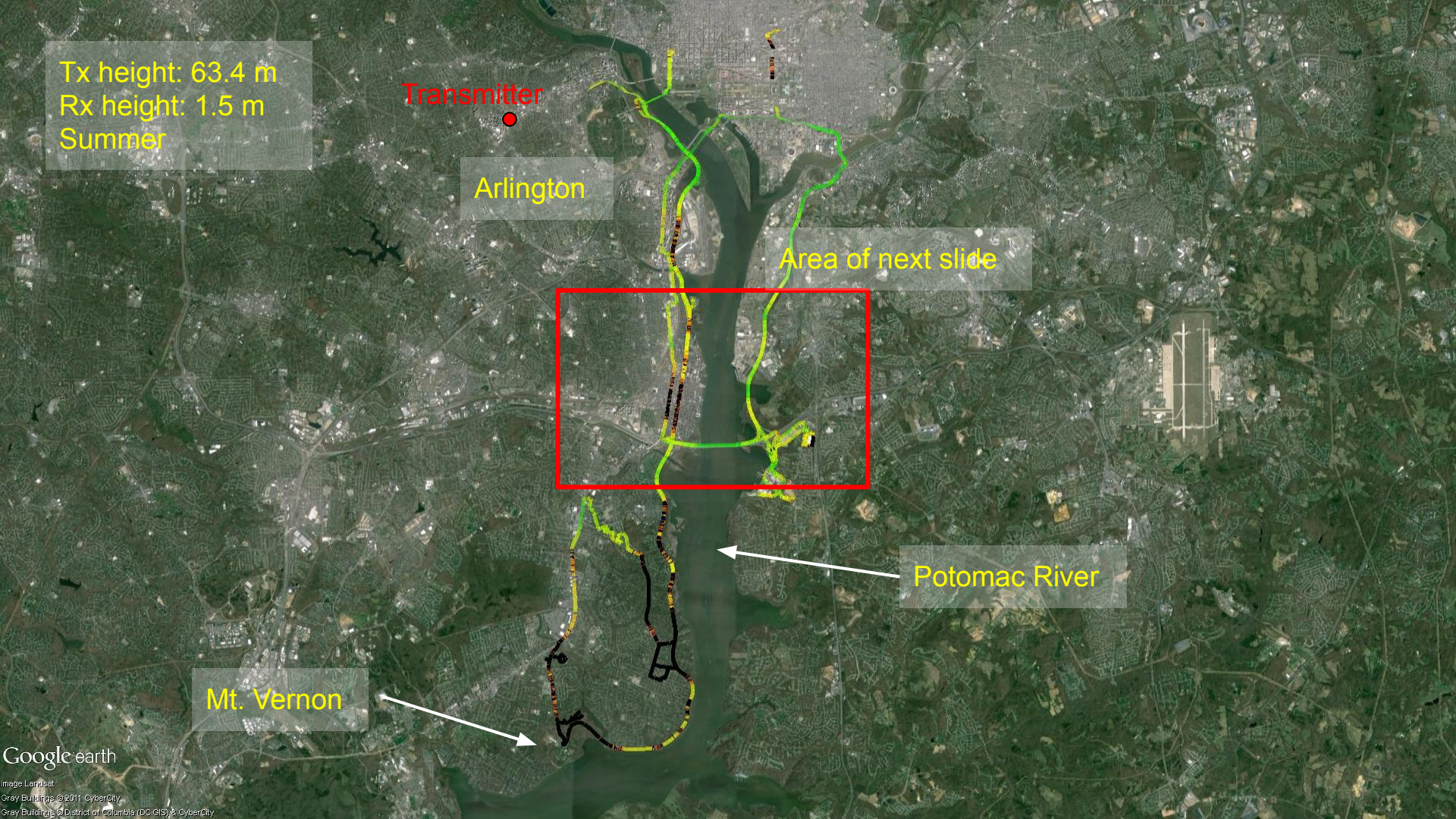
N38.88421908W77.104641282



Tx & Rx Stationary
Light-to-moderate rain
Tx height: 33.1 m (indoors)
Rx height: 1.5 m
Pathlength: 1.7 km
Number of measurements: 463
Measurement Time: ~10 minutes.
Measured loss: 171.1 +/- 1.4 dB
L-R prediction: 181.6 dB
Difference: -10.5 dB



Graphical Examples of Propagation Phenomena


Tx height: 63.4 m
Rx height: 1.5 m
Summer
Transmitter
Arlington
Area of next slide
Potomac River
Mt. Vernon
Google earth
image Landsat
Gray Buildings © 2011 CyberCity
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Transmitter ~ 10-12 km
Clear effect of clutter/building losses when traversing Old Towne Alexandria
Signal picks up nicely along river south of Old Towne
Google earth
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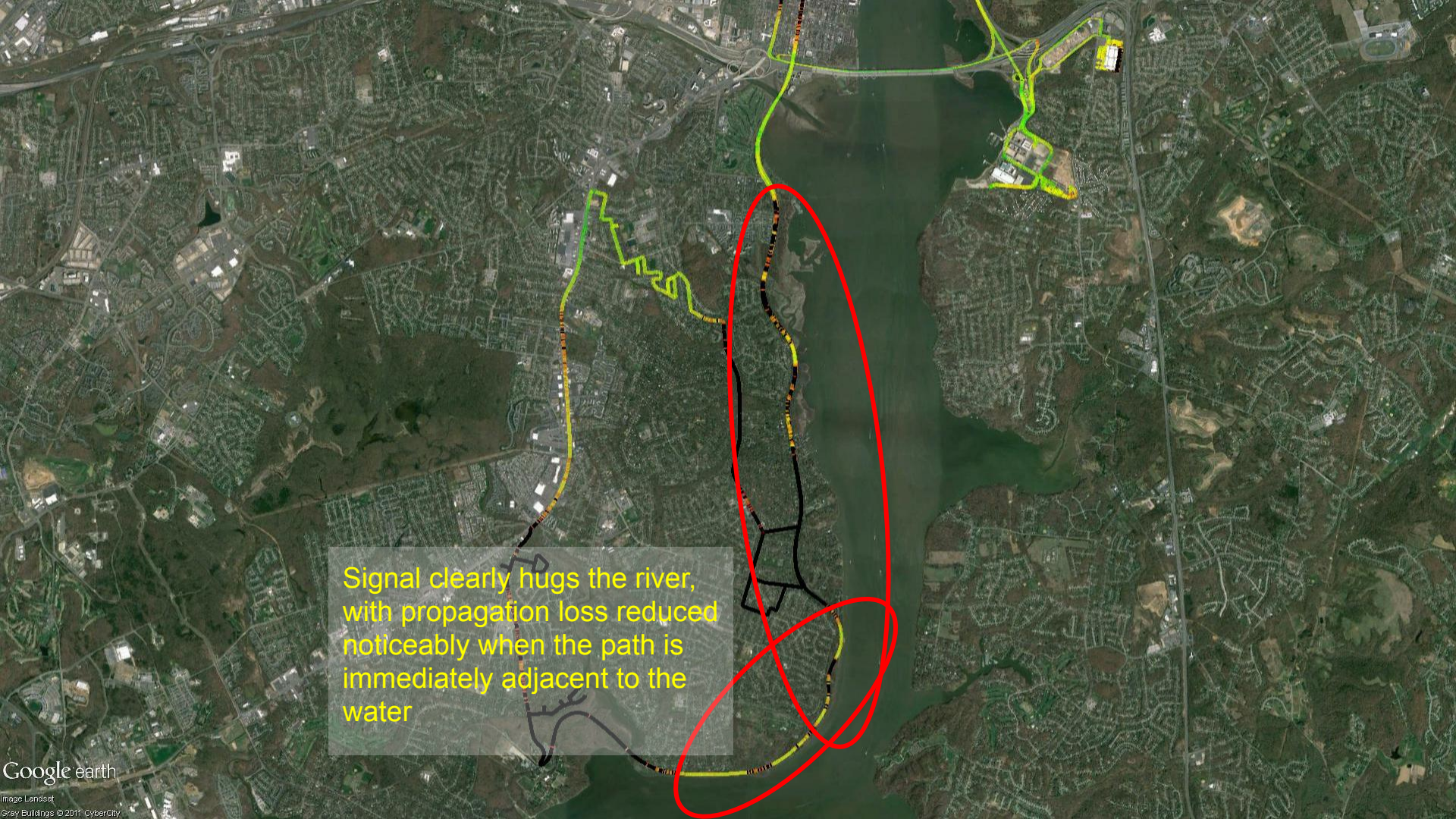
Signal clearly hugs the river, with propagation loss reduced noticeably when the path is immediately adjacent to the water
Google earth
Image Landsat
Gray Buildings © 2011 CyberCity


Transmitter ~ 19 km
Signal “hugs the river”
Immediate substantial loss of signal when small amount of land/trees is between receiver and river
Google earth

Some Tentative Takeaways

- Measured loss is almost always greater than Longley-Rice prediction. The difference is especially pronounced within the clutter layer.
- Agreement with L-R improves with distance, but subject to significant selection bias, and requires further testing
- Agreement with L-R improves somewhat with transmitter height above ground and in relation to surrounding clutter
- Indoors accounts for about 15 dB of additional loss
- No appreciable difference due to light-to-moderate rain or snow
  - Significant difference in heavy rain for indoor tx, but needs further study
- Some propagation anomalies noted
  - Signals travel well down-river
  - Trees create significant scattering/absorption