Understanding the Impact of Terrain Databases on the Irregular Terrain Model

Chriss Hammerschmidt, Robert Johnk
Institute for Telecommunication Sciences
NTIA
Boulder, CO, USA
chammerschmidt@its.bldrdoc.gov

***Abstract*— This paper discusses a mobile propagation measurement in Los Angeles, CA and compares these measurements to the output from the Irregular Terrain Model (ITM). Propagation measurements are currently being used at the Institute for Telecommunication Sciences (ITS) to improve and validate the ITM propagation model. In this paper, these measurements are compared to the predicted terrain attenuation losses from ITM as a function of four different terrain databases. We began using ITM to calculate clutter losses (i.e. attenuation due to vegetation and man-made structures) by subtracting the ITM prediction from the measured data. As with any model, the estimation of clutter losses changes as the prediction from ITM changes based on the terrain database; therefore, it is important to understand why these changes occur. This paper briefly discusses the measurement system, the results from this campaign, and the output from ITM as a function of four different terrain databases of various horizontal resolutions.**

***Keywords*— attenuation, Fresnel zone, ITM, mobile propagation, terrain databases**

I. Introduction

Spectrum sharing and dynamic spectrum access issues have been addressed at the Institute for Telecommunication Sciences (ITS) since 1998 [1], [2]. In July 2012, the Commerce Spectrum Management Advisory Committee (CSMAC) began a series of working group meetings between federal agencies and commercial wireless operators to investigate the feasibility of sharing spectrum between commercial and federal systems [3]. The assumptions used in these meetings led to rule-makings for spectrum sharing scenarios in the 1755-1780 MHz band. Both the commercial sector and the federal agencies understood that follow-on propagation measurements were needed to refine models used in the initial CSMAC analysis. ITS has been providing these propagation measurements in various cities since 2014, both to improve our propagation model and to assist the federal agencies in further understanding the propagation environment and exploring improvements to their models.

ITS uses the ITS-developed Irregular Terrain Model (ITM) and some federal agencies use the Terrain-Integrated Rough Earth Model (TIREM) to estimate terrain-attenuation losses. Both of these models require terrain path profiles extracted from terrain databases to estimate reflection, diffraction, and scattering losses. Not only do the terrain databases available today have better horizontal resolution than those available when ITM and TIREM were first developed, but the calculations used to extract the vertical resolution have significantly improved since then. As ITS works to understand propagation measurement uncertainties and to improve ITM, we are taking another look at the impact of terrain databases on estimates of terrain attenuation.

Not included in either ITM or TIREM is an extra term to estimate losses from vegetation or man-made structures (i.e. clutter losses). In this regard, a recent development is the use of Light Detection and Ranging (LIDAR) technology to measure the location and dimensions of vegetation and man-made structures and thus increase propagation model accuracy. The horizontal resolution of these databases approaches 1 meter (m). However, these databases are not complete across the United States so other databases are needed to supplement the LIDAR information. As ITS works to not only improve terrain diffraction loss estimates by using better terrain databases, but also to develop a newer model which will include the effects of clutter, we will begin to better understand the entire propagation environment.

Section II briefly describes the measurement system, setup, and the post-processing used to obtain basic transmission gain (BTG). Section III briefly discusses the ITM model and how it predicts terrain attenuation. A discussion of the measurement setup and the results are given in Section IV. Section V takes the measurement results and the results from the ITM model for four different terrain databases and shows how the ITM model uses the terrain to make terrain attenuation prediction.

II. Measurement System

A. Equipment & Setup

The measurement system is composed of transmitting and receiving equipment [4], [5]. The transmitting equipment includes a signal generator, a rubidium oscillator, a power amplifier, a directional coupler, a power meter, and an omni-directional antenna. This equipment is housed either in a cellular-on-wheels (COW) trailer or in the ITS Radio Spectrum Measurement System truck. Both the COW and the truck are outfitted with equipment racks, air conditioning, and power generation capabilities. A schematic of the transmitting equipment is shown in Fig. 1 and a photograph of the COW, on-site at the transmitting location, is shown in Fig. 2. The COW's mast is raised to a full height of approximately 18 m above ground level (AGL).

Funding for these measurements was provided by the Defense Spectrum Office, IAA Number DSO-16-006-0000-00.

This paper was presented at and will appear in the Proceedings of the 2017 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI), Washington DC, 7-11 Aug. 2017.

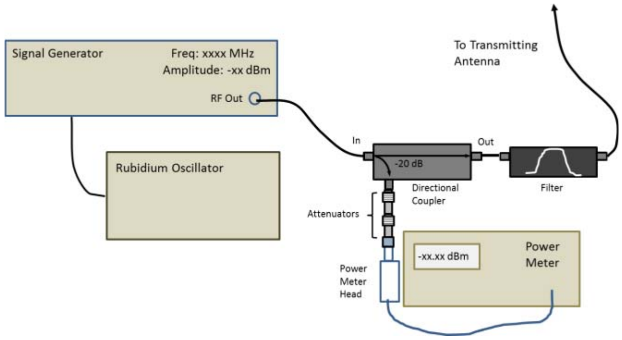

Fig. 1. Transmitting equipment.

The receiving equipment is typically housed in a measurement van during the testing. The receiving system consists of a vector signal analyzer (VSA), a spectrum analyzer (SA), a power divider, a rubidium oscillator, an omni-directional antenna, and a computer to store the data. Fig. 3. shows a schematic of the receiving equipment. The SA is equipped with an on-board Global Positioning System (GPS) receiver to record latitude and longitude during data collection. The GPS antenna is connected to an SA port and is placed on the roof of our vehicle. Fig. 4 shows a photograph of the measurement van.

As the signal is transmitted into the environment, the receiving antenna captures the signal, which is then split and measured by both the SA and the VSA. There is a time lag between the VSA and SA due to the lag in start times between the two instruments. The VSA has a larger dynamic range than the SA, however it does not contain an internal GPS receiver and so the SA data is used to align the GPS signals with the VSA data. This alignment is discussed in the next section.

B. Data Post-Processing

The SA data is processed separately from the VSA data and then the two are aligned as discussed in the following paragraphs. The SA and GPS data for each sweep is stored as a log magnitude array and string array, respectively, in a Matlab® event data structure.

The VSA raw in-phase and quadrature (I-Q) parameters are also written to a Matlab® file. Data saved into this file includes the sampling time, the frequency information, and the complex I-Q data pairs. During this processing step, the magnitude of the raw I-Q data measured by the VSA is smoothed over a 500 ms window to approximate a 40 wavelength driving distance [6], [7]. The smoothed power is time-shifted to align the VSA and SA data. A linear regression model is then used to minimize the residuals between the two data sets.

Fig. 2. Transmitting location at Griffith Park.

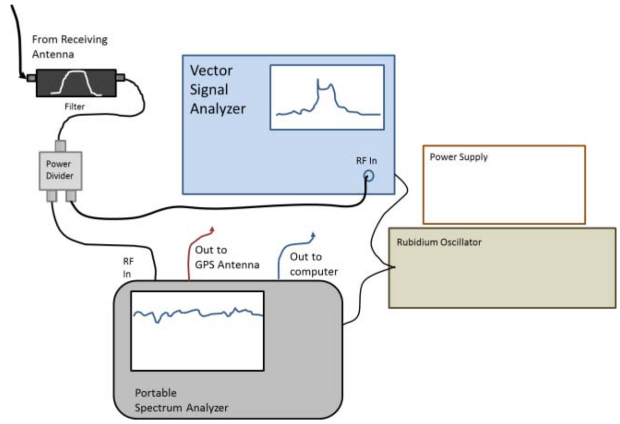

Fig. 3. Receiving equipment.

The alignment of the VSA power and the SA power vs. the elapsed time in seconds for a portion of the drive run is shown in Fig. 5. This alignment allows the GPS time stamp from the SA mean power to be transferred to the data points in the VSA average smoothed power data series. This data is then saved and used in the Longley-Rice/Irregular Terrain Model (ITM) which will be discussed in the next section.

III. ITM Model Discussion

ITM was developed at ITS as a general purpose radio propagation algorithm [8]. The model was developed to predict median signal strength as a function of distance. The model is valid from 20 MHz to 20 GHz and for distances greater than 1 km. ITM calculates propagation variabilities which are computed for location and time. The model was developed from electromagnetic principles, statistical analyses of terrain features, and measurements. There are two operational modes for the algorithm: the area-prediction mode, and the point-to-point mode. We will focus on the point-to-point mode and its associated parameters for this discussion. We will touch briefly

Fig. 4. Photograph of the receiving van.

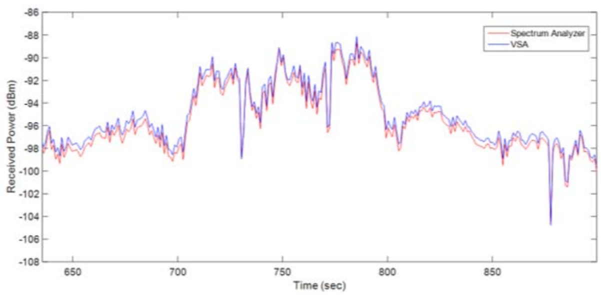

Fig. 5. Alignment of VSA and SA data files.

on the input parameters and some of the output parameters in this paper, but for a more detailed discussion of the algorithm refer to [8], [9].

The input parameters to the model are the transmitting and receiving heights, the ground impedance, the climate, and a terrain path profile. Using the latitude and longitude of the transmitting and receiving antennas (terminals), terrain profiles between the transmitting and receiving locations are extracted for the model analysis. This terrain profile and distance are then used to calculate the terrain irregularity parameter (i.e. the inter-decile range of profile elevations along the geodesic between the terminals and the smooth earth horizon distance from each of the terminals). The final output of the model is the reference attenuation, A_{ref}, which is a piecewise, continuous function of the path distance for three ranges: (1) the line-of-sight range, (2) the diffraction range, and (3) the scatter range. Two distances in the diffraction range are used to calculate two diffraction attenuations based on both Epstein-Peterson knife-edge diffraction and smooth-earth horizon diffraction models. The slope and attenuations from the diffraction range are used to calculate two attenuations in the line-of-sight (LOS) range based on two distances in this range. Finally, if the measurement distance is greater than a calculated distance in the scattering region, then a tropospheric attenuation is calculated and all of these are combined to obtain A_{ref} and added to the free-space path loss to obtain the modelled attenuation. For our purposes, we currently use this modelled attenuation to obtain a clutter metric which we define as the difference between the ITM model and the measured basic transmission gain (BTG). BTG is the negative of basic transmission loss (BTL).

IV. Measurement Discussion & Results

A. Measurement Results

Measurement results will be shown for one measurement route from the Griffith Park area (the transmitting location) in Los Angeles to receiving locations along a route from Griffith Park into Downtown Los Angeles. The geography along the route ranges from mountainous terrain near the transmitting location, residential and commercial developments in the Los Angeles basin, to the high-rise, urban corridor of downtown Los Angeles. The latitude and longitude coordinates for the transmitting location are 34.126119 N and 118.306953 W at an elevation of 361 m. A graph of the measured and modelled data is shown in Fig. 6. This figure shows BTG, in dB, for measured data (×), the ITM model (○), and the free-space transmission gain (─). The terrain database used to generate the ITM model in Fig. 6 was the United States Geological Survey (USGS) National Elevation Data (NED 1 sec) [10]. Notice that at some locations, the ITM-modelled BTG predicts propagation losses greater than the measured value. There are two reasons for this, 1) ITM is predicting too much terrain attenuation for that location and should be adjusted, or 2) there are other propagation paths that combine at the antenna constructively and are not being modelled correctly by ITM's 2-D terrain path profile algorithm. We will look at a few of these areas in the next section. Fig. 7 shows the geo-located measured BTG along our drive route. The magenta star denotes the location of the transmitting antenna. Areas of high BTG (high received signal levels) are shown by the pink circles and areas of low BTG are shown by the purple circles. The downtown area is shown in the lower-right corner.

B. Predicted Terrain Attenuation

We compare measurement data at four receiving locations along the drive route to ITM output generated using four terrain databases. Two of these locations were at the bottom of the hill just outside Griffith Park, shown by the black x's in Fig. 7. The other two locations were in Downtown Los Angeles, shown by the white x's in Fig. 7. The terrain databases used for the following analysis are:

- Shuttle Radar Topographic Mission (SRTM─Level-1─90m), 3 arc-second grid spacing, Interferometric SAR data source
- USGS National Elevation Data (USGS─NED-1─30m), 1 arc-second grid spacing, 1:24,000 contour line data source
- LIDAR-derived Digital Elevation Model, 1/3 arc-second grid spacing, 1 m LIDAR Army Geospatial Center (AGC), extracted using a 30 m resolution and 10 m resolution, (LIDAR─AGC─30m, LIDAR─AGC─10m)

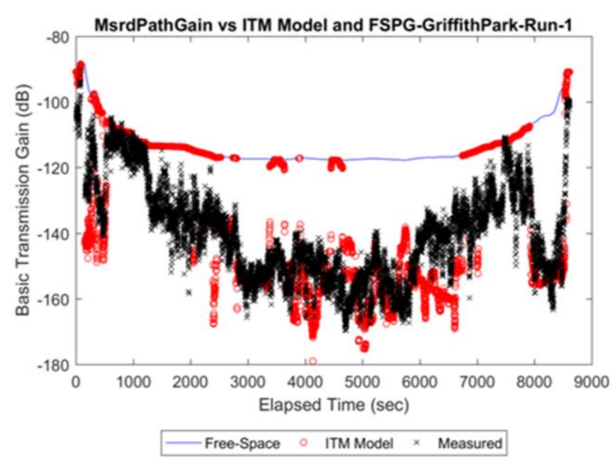

Fig. 6. Measured BTG (x), ITM-modelled BTG (○), and free-space transmission gain (─).

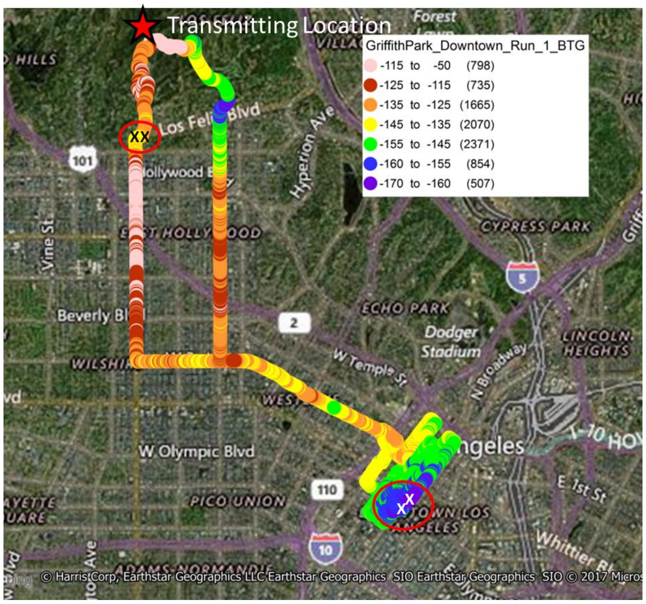

Fig. 7. Geo-located, measured BTG along drive route. MapInfo® image.

A summary of the predicted attenuation for the measured BTG data, free-space transmission gain, and the four ITM terrain database BTG outputs is shown in Table I for each of the four measurement locations. We will now discuss each of these locations in greater detail.

TABLE I. COMPARISON BETWEEN MEASUREMENT BTG DATA, FREE-SPACE AND ITM BTG OUTPUT FOR FOUR TERRAIN DATABASES.

Source	**Measured and Predicted Basic Transmission Gain (dB)**			
	454.56 sec	***469.01 sec***	***4583.38 sec***	***4661.81 sec***
Measurement data (─)	−131.67	−139.51	−149.96	−153.47
Free-space (• • •)	−103.25	−103.42	−117.79	−141.46
USGS─NED-1─30m (+)	−103.25	−128.93	−117.78	−144.43
SRTM─Level-1─90m (*)	−103.01	−103.19	−159.95	−164.88
LIDAR─AGC─30m (●)	−103.25	−106.96	−117.80	−140.76
LIDAR─AGC─10m (×)	−103.34	−133.60	−117.80	−141.46

Fig. 8 shows measurement data taken on a portion of the drive route shown in Fig. 6 from 440 to 540 elapsed seconds. We examine the first two outlined data points on this graph in more detail. The first set of blue outlined data points corresponds to an elapsed drive time of 454.56 sec. Four terrain database profiles, shown in Fig. 9, were imported into the ITM model to obtain BTG: (a) USGS─NED-1─30m with a 30 m horizontal resolution (+), (b) SRTM─Level-1─90m with a 90 m horizontal resolution (*), (c) LIDAR─AGC─30m [11] with a horizontal resolution of 30 m (●), and (d) LIDAR─AGC─10m with a horizontal resolution of 10 m (×). The terrain profile extracted from the database is shown by the black trace (─), and the free-space transmission gain is shown by the light-blue, dotted trace (• • •). For all of the profiles at this location, the terrain databases are showing there is no terrain interaction between the transmitting and receiving antenna and therefore ITM should predict no terrain attenuation and return a value of free-space transmission gain, which it does.

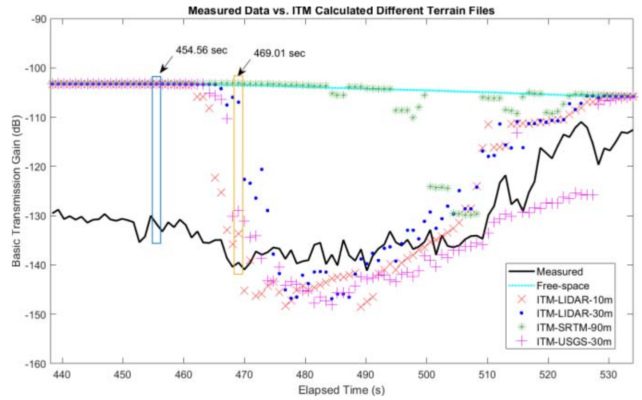

Fig. 8. Measured BTG, free-space transmission gain, ITM model for four terrain databases from point 460 to point 560.

The next set of orange outlined points is shown in Fig. 10 at an elapsed time of 469.01 seconds. Four different values of terrain attenuation were predicted by ITM: (a) for the USGS─NED-1─30m profile, ITM predicted a BTG −128.93 dB, (b) for the SRTM─Level-1─90m terrain profile, ITM predicted no terrain attenuation, or free-space path loss, −103.19 dB, (c) for the LIDAR─AGC─30m terrain profile, ITM predicted a BTG of −106.96 dB, and (d) for the LIDAR─AGC─10m terrain profile, ITM predicted a BTG of −133.60 dB. The measured data shows a measured value of approximately −139.51 dB. Why the differences between the various databases? The terrain profiles in Fig. 10 and a discussion of how ITM analyzes the profile may provide insight.

The first thing we notice in (b) is the first Fresnel zone does not intersect the SRTM─Level-1─90m terrain profile. This explains why ITM predicted no terrain attenuation or a free-

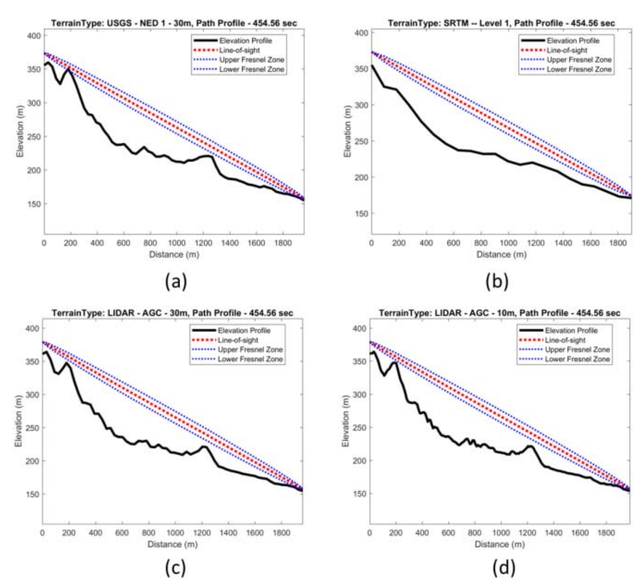

Fig. 9. Terrain profiles at the receiving location corresponding to an elapsed drive time of 454.56 sec.

space transmission gain value using this database. The USGS─NED-1─30m profile crosses the Fresnel zone and the LOS line at approximately 180 m, 1800 m, and 1900 m. When ITM processes the terrain data, it steps along the profile both from the transmitting antenna and from the receiving antenna and looks for a point that is higher than either transmitting or receiving location, when it finds this point, it saves both the elevation angle and the position of that point and uses this distance as the horizon distance and adds the two elevation angles. For the USGS─NED-1─30m profile, the highest location from the transmitting location is shown by the orange arrow at about 180 m and the highest location from the receiving location is shown by the green, dotted arrow at approximately 1800 m. The combined elevation angle is 0.006 radians (rads). The LIDAR─AGC─30m did not show any elevation higher than either the transmitting or receiving location, but it did compute a small amount of attenuation compared to the free-space value, most likely due to crossing into the first Fresnel zone. The LIDAR─AGC─10m crosses the Fresnel zone and the LOS line from about 1740 m to 1800 m, and again at about 1850 m. As ITM searches this terrain database it finds that the highest elevations from the transmitting location are at distances of approximately 1741 m and 1872 m (see Fig 10(a)). The combined elevation angle is 0.014 rads. The elevation angle for the LIDAR─AGC─10m is larger which means that the terrain would block more of the radio energy at the receiving location than predicted by the USGS─NED-1─30m, which explains the higher calculated BTG.

We also ran ITM for two receiving locations in Downtown Los Angeles, one at an elapsed time of 4583.39 s and one at an elapsed time of 4551.81 s. The results in Fig. 6 from point 4790 to 4875 are shown in Fig. 11 and the points to be analyzed are shown by the outlines. The terrain profiles for the first downtown location are shown in Fig. 12 and the terrain profiles for the second downtown location are shown in Fig. 13.

For the first location, ITM processed the USGS─NED-1─30m, the LIDAR─AGC─30m, and the LIDAR─AGC─10m terrain profiles and did not find any location along the terrain profile that was higher than the transmitting or receiving locations. For the first location, the SRTM─Level-1─90m (Fig. 13 (b)) ITM output found that the highest elevations from the transmitting location are at distances of approximately 9689 m and 10220 m. The computed elevation angle is 0.041 rads. Fig. 13 shows the terrain profiles for the location at 4661.81 secs. ITM found that for all terrain databases the highest elevation for both the transmitting and receiving location occurred at the same location along the profile. We also notice that the BTG predictions from the USGS─NED-1─30m, the LIDAR─AGC─30m, and the LIDAR─AGC─10m predict similar attenuation values with elevation angles of 0.003, 0.0014, and 0.0011 rads, respectively. The SRTM─Level-1─90m terrain profile has the highest attenuation value and highest elevation angle with a value of

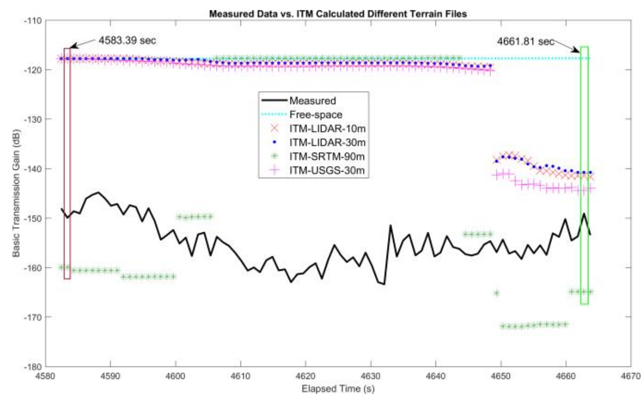

Fig. 11. Measured BTG, free-space transmission gain, ITM model for four terrain databases from point 4790 to point 4875.

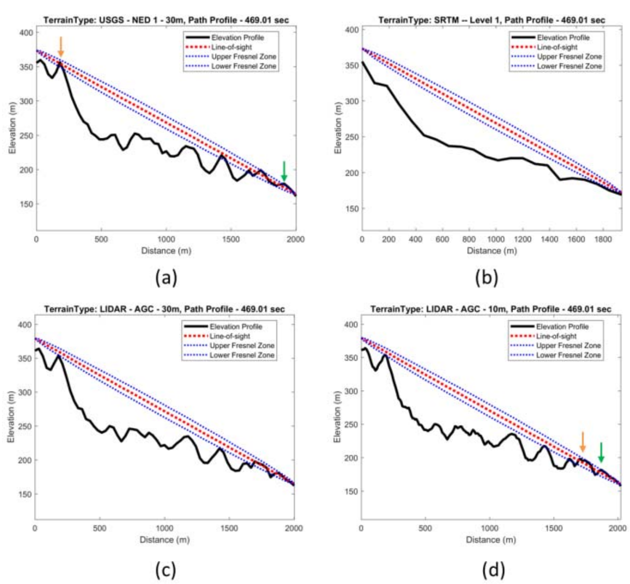

Fig. 10. Terrain profiles at the receiving location corresponding to an elapsed drive time of 469.01 sec.

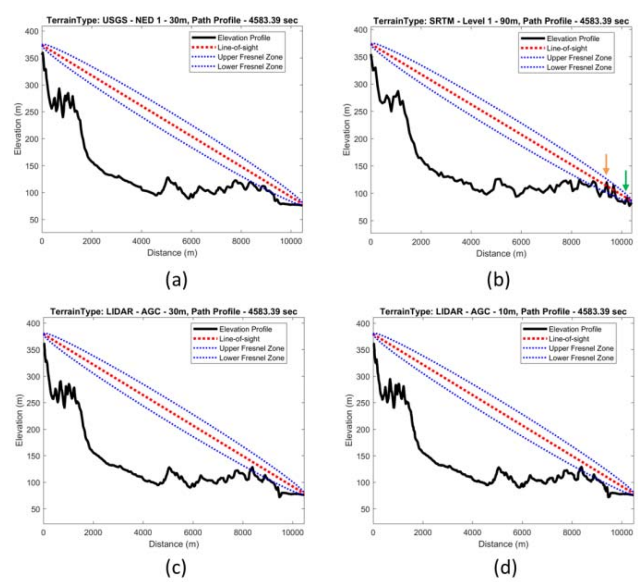

Fig. 12. Terrain profiles at the receiving location corresponding to an elapsed drive time of 4583.39 sec.

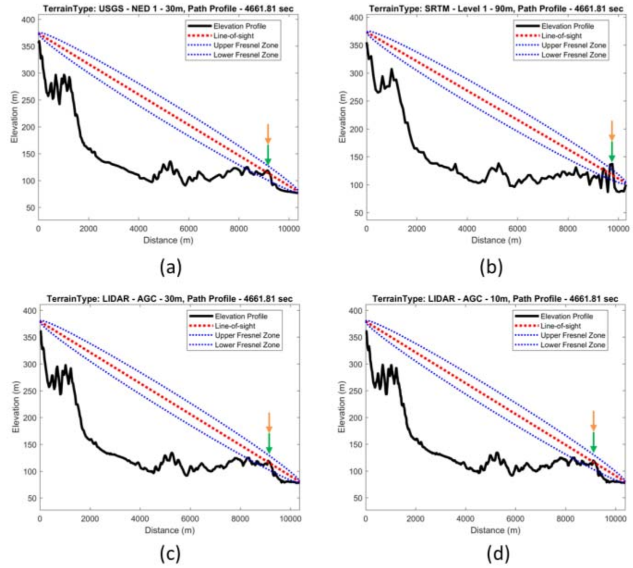

Fig. 13. Terrain profiles at the receiving location corresponding to an elapsed drive time of 4661.81 sec.

0.06 rads due to the observed terrain blockage. We can see that the elevation angle influences the predicted attenuation value for all the other ITM predictions of BTG. The SRTM─Level-1─90m terrain profile is so different from the others, it warrants further exploration of this difference.

SRTM─Level-1─90m data was generated with interferometric synthetic aperture radar (IFSAR) flown on the Shuttle Radar Topography Mission (SRTM) in February 2000 [12]. Reflected radar signal returns from the tops of buildings and forest canopies produce a "reflective surface" rather than a "bare earth" surface. This IFSAR-derived DEM has noise-induced errors ranging from 3 to 5 meters of height. The USGS─NED-1─30m data is a product of the U.S. Geological Survey that is derived from the contour lines portrayed on a 1:24,000 topographic map. Considerable effort has been made to compile these contour lines on "bare earth" resulting in a smoother, well-defined terrain surface. The 10 meter and 30 meter DEM are derived from high-resolution 1 meter LIDAR data acquired by the U.S. Army Geospatial Center (AGC). In this case, the noise-induced "lumpiness" in the SRTM data predicts greater attenuation than the other elevation models, but that is not indicative of a more accurate terrain attenuation prediction [13].

V. Conclusion

We have shown how the use of different terrain databases can affect the results from the ITM model that tries to predict attenuation due to diffraction losses. We found that ITM can distinguish between areas where terrain interacts with the first Fresnel zone and where it does not. The quality of the terrain database has an effect on the attenuation prediction and elevation angle. Generally, the terrain databases derived from contour lines and those processed from LIDAR acquisition data are smoother than those derived from IFSAR data. Care must be taken to understand the inherent errors in different terrain databases and how they affect a model's prediction.

Acknowledgment

Funding for these measurements was provided by the Defense Spectrum Office, IAA number DSO-16-006-0000-00.

References

[1] NTIA, "ISART 1998," https://www.its.bldrdoc.gov/isart/past-programs/1998-isart-speaker-slides.aspx, accessed March 2017.

[2] NTIA, "ISART 2011 Proceedings─developing forward thinking rules and processes to fully exploit spectrum resources: an evaluation of radar spectrum use and management," NTIA SP-12-485, July, 2011.

[3] CSMAC, "Working Group Reports, 2014," http://www.ntia.doc.gov/files/ntia/publications/wg5_final_report_posted_03042014.pdf, accessed January 21, 2016.

[4] C. A. Hammerschmidt, R. T. Johnk, "Extracting clutter metrics from mobile propagation measurements in the 1755-1780 MHz band," Milcom 2016, Baltimore, MD, November, 2016.

[5] R. T. Johnk, C. A. Hammerschmidt M. A., McFarland, J. J. Lemmon, "A fast-fading mobile channel measurement system," IEEE Conf. Electromag. Compat. 2012, pp. 584-589.

[6] R. T. Johnk, "A high-performance CW mobile channel sounder," IEEE Conf. Electromag. Compat. 2017, unpublished.

[7] J.D. Parsons, "The mobile radio propagation channel," New York, NY, John Wiley & Sons, 1992.

[8] P.L. Rice, A.G. Longley, K.A. Norton, and A.P. Barsis, "Transmission loss predictions for tropospheric communication circuits," U.S. Department of Commerce, Natl. Bur. of Stand., Technical Note 101, Vols. I & II, (Revised January 1, 1967).

[9] E. Drocella, J. Richards, R. Sole, F. Najmy, A. Lundy, P. McKenna, "3.5 GHz exclusion zone analyses and methodology," Natl. Telecomm. Infor. Admin., NTIA-TR-15-517, Appendix A, (Reissued March 2016).

[10] United States Geological Survey, "The National Map," https://viewer.nationalmap.gov/basic, accessed January, 2017.

[11] Army Geospatial Center, http://www.agc.army.mil/Missions/Terrain/, accessed March 2017.

[12] NASA-JPL-CIT, "Shuttle Radar Topography Mission," http://www2.jpl.nasa.gov\strtm, accessed March 2017.

[13] G. Lukes, Institute for Defense Analysis, private communication, May 2016.