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ASSESSMENT OF THE HYBRID PROPAGATION MODEL

VOLUME 2: COMPARISON WITH THE INTEGRATED NOISE MODEL

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13. ABSTRACT (Maximum 200 words)
This is the second of two volumes of the report on the Hybrid Propagation Model (HPM), an advanced prediction model for aviation noise propagation. This volume presents comparisons of the HPM and the Integrated Noise Model (INM) for conditions of uneven terrain. The cases explored in this volume correspond to flat, hill, upward sloping, and downward sloping terrain presented in Volume 1 (Cases 1, 5, 6, and 7, respectively) to test the capabilities of the HPM. The results are analyzed in detail and comparisons are made between the HPM and INM results for the uneven terrain conditions. The goal of this research is to enhance the modeling capabilities of the AEDT/INM, particularly in complicated environments such as National Parks.

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1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
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1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
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1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
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1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup ©	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
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1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
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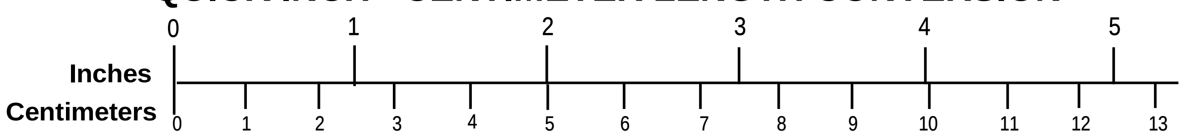

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. SD Catalog No. C13 10286

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1. INTRODUCTION

The hybrid propagation model (HPM)[1,2] is a numerical model designed to predict aviation noise levels under complicated propagation conditions. The goal of this research is to enhance the modeling capabilities of the AEDT/INM in complex environments, such as National Parks. The model was originally developed in a research effort at the Pennsylvania State University in cooperation with the Volpe National Transportation Systems Center and the Federal Aviation Administration (FAA). HPM is a composite of three propagation methods: a parabolic equation (PE) model; a fast field program (FFP); and a straight ray-trace model.

This report is the second of two volumes. The first volume of this report presents a study of various propagation conditions run by HPM and its component models (the full HPM, pure FFP, and a pure ray model). This volume presents a comparison between the HPM and the FAA's Aviation Environmental Design Tool (AEDT) and Integrated Noise Model (INM) for four of the eleven cases introduced in the first volume of the report. The four cases focus on conditions of uneven terrain, for which INM is capable of including propagation effects, and exclude other types of propagation conditions, such as refractive atmospheres or ground impedance transitions, which INM currently does not incorporate.

More detailed descriptions of the HPM's component models and programming implementation can be found in the "Assessment of the Hybrid Propagation Model, Volume 1: Analysis of Noise Propagation Effects" report[3]. In depth explanations of the physical causes of certain characteristics of the noise predictions can also be found in the first report volume. This volume focuses, instead, on the analysis of the differences between the HPM and INM predictions.

2. COMPARISON BETWEEN HPM AND INM RESULTS

The conditions modeled in this analysis are the same as those modeled in Volume 1 and will, therefore, be referred to by the case numbers assigned to them in that report. A base case is presented first (Case 1), as a control condition for the remaining cases. The base case includes a flat, soft ground and a homogeneous atmosphere. Since INM is capable of including the effects of a line-of-sight blockage between source and receiver, a comparison is made between INM and HPM results for the uneven terrain condition cases. Uneven terrain cases—hill (Case 5), upward sloping terrain (Case 6), and downward sloping terrain cases (Case 7)—demonstrate differences in the incorporation of terrain effects between the two models.

Results are presented as a function of horizontal range from the source for a receiver at a given height above the ground. Diagrams of the geometries of each case are shown below the results figures. Four source heights are considered for each case. The common parameters are listed below.

- Source heights (measured from the ground surface directly below): 10, 40, 100, 400 m
- Source noise and performance data*: 747-400 overflight, 7444 lbs thrust, the A-weighted maximum sound level (LAMAX) metric
- Receiver height (above the ground surface): 1.219 m
- Soft Ground: Effective flow resistivity of 150 cgs Rayls
- Temperature: 14.9 °C

The algorithms used to incorporate the effect of terrain in the INM are based on the path length difference between a direct path from source to receiver, and the path over the top of the terrain feature.[4] The PE, responsible for including terrain effects into the HPM, uses a coordinate transformation that follows the surface of the ground. It is limited to smoothly varying terrain with local slopes of less than approximately 30 degrees.[5] The comparisons show the conditions under which differences are expected, as well as the extent of these differences.

One difference between the models, in implementation rather than methodology, is the atmospheric absorption coefficients applied by the INM and HPM. Coefficients from two different standards, SAE-AIR-1845 and SAE-ARP-866A, were used to calculate results for the Base Case 1, labeled “INM Baseline” and “INM Atm Abs” in Figure 1, respectively. The other cases use only the coefficients specified in SAE-AIR-1845, representative of average atmospheric conditions, for the INM calculations. The HPM uses atmospheric absorption coefficients based on equations in Bass, et al.[6], which are functions of frequency, relative humidity, and absolute temperature in kelvins.

* HPM source noise data are developed from INM/AEDT source data [Noise-Power-Distance (NPDs) curves and spectral class]. The appropriate spectral class data are calibrated to aircraft-specific NPD at 1000 ft (305 m). The calibrated spectra are then propagated back to a distance of 1 m from the source using the method described in SAE-AIR-1845 and FAR 36, assuming the ICAO standard atmosphere.

2.1 Base Case 1: Soft, Flat Ground, Homogeneous Atmosphere

Base Case 1 uses the simplest set of propagation conditions: a soft, flat ground with a homogeneous atmosphere. It serves as the baseline for evaluating the added effects of more complicated terrain.

Figure 1 shows the INM and HPM results plotted for Base Case 1 (flat, soft ground with a homogeneous atmosphere) for the 4 different source heights. As discussed above, the two INM curves represent the two different atmospheric absorption implementations. For each source, levels decrease with distance, resulting from geometrical spreading, atmospheric absorption and the effect of the soft ground. Some fluctuations in level calculated with HPM can be seen for all four sources, especially toward the lower ranges, as a result of the interference patterns of the discrete frequencies. The combination of the twenty-four one-third octave band results, however, blends the severe interference pattern peaks and dips of the individual frequency bands and produces a smoother overall level.

The comparison shows good agreement between the INM and HPM at the smallest ranges, near the source. However, for the lowest altitude, the 10 m source, the two models deviate at approximately 90 m, with the HPM showing a more gradual drop off and reporting higher levels. A zoomed-in figure of the smaller ranges of the 10 m altitude source is shown in Figure 2. After its initial drop, HPM results show a more moderate decrease, whereas INM results decrease more gradually over the full propagation range. At approximately 1400 m, the results cross and the HPM predicts lower levels for the remainder of the range. A similar pattern is seen for the 40 m source. Here, however, it takes the full 3 km for the two models to meet again. HPM has higher predictions at the highest two sources, 100 and 400 m, maintaining a fairly constant difference relative to INM, for most of the propagation range. A small difference is seen between the results of the two atmospheric absorption standards conditions of the INM; however, the difference is only about 1.4 dB at 3 km. Therefore, the general trends are similar.

Alternatively, plotting the same INM results against HPM results for a downward refracting atmosphere (Case 4) with a logarithmic sound speed profile, as shown in Figure 3, offers a closer match in the pattern of results across the propagation range. While the HPM results generally remain higher than INM predictions, the rate of decrease in level across the range is very similar. The INM does not allow a user to specify refractive characteristics of an atmosphere. However, the lateral attenuation adjustment is included in INM calculations to account for the effect of ground reflections, refraction-scattering effects, and airplane shielding effects. This adjustment term may cause results to resemble propagation through a downward refracting atmosphere more closely than a homogeneous atmosphere.

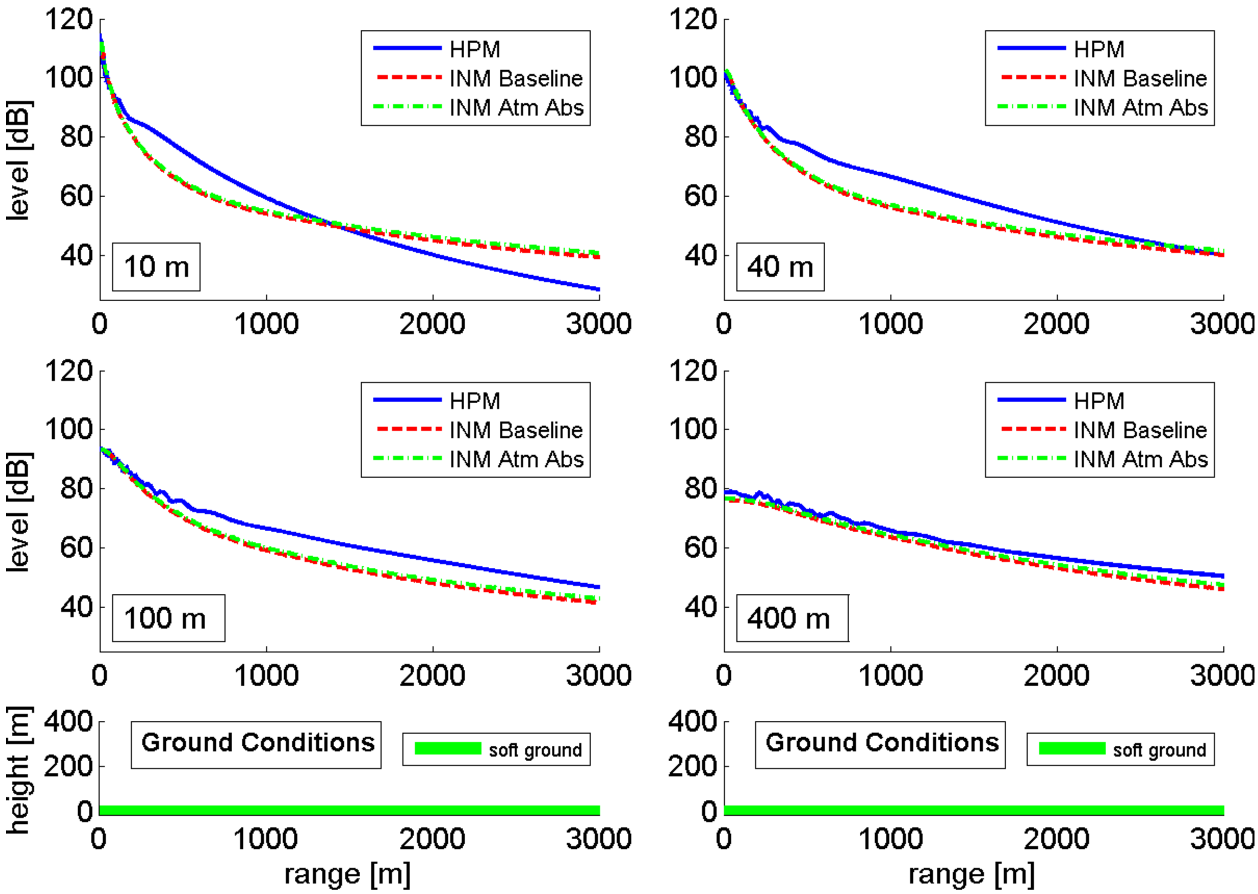

Figure 1. Case 1— Soft, flat ground and homogeneous atmosphere. HPM and INM results are shown for each source height—10 m, 40 m, 100 m, and 400 m. A diagram of the propagation conditions is included beneath the results figures.

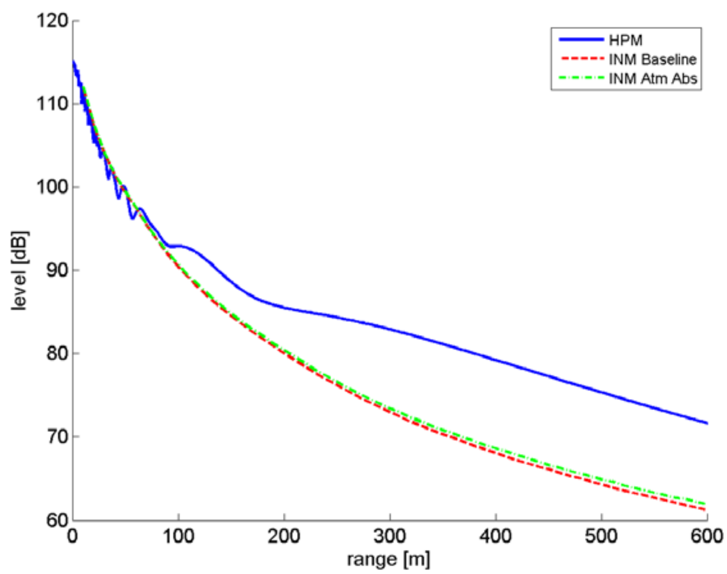

Figure 2. Case 1— Soft, flat ground and homogeneous atmosphere. HPM and INM results are shown, zoomed into a range of 0 to 600 m for the 10 m altitude source.

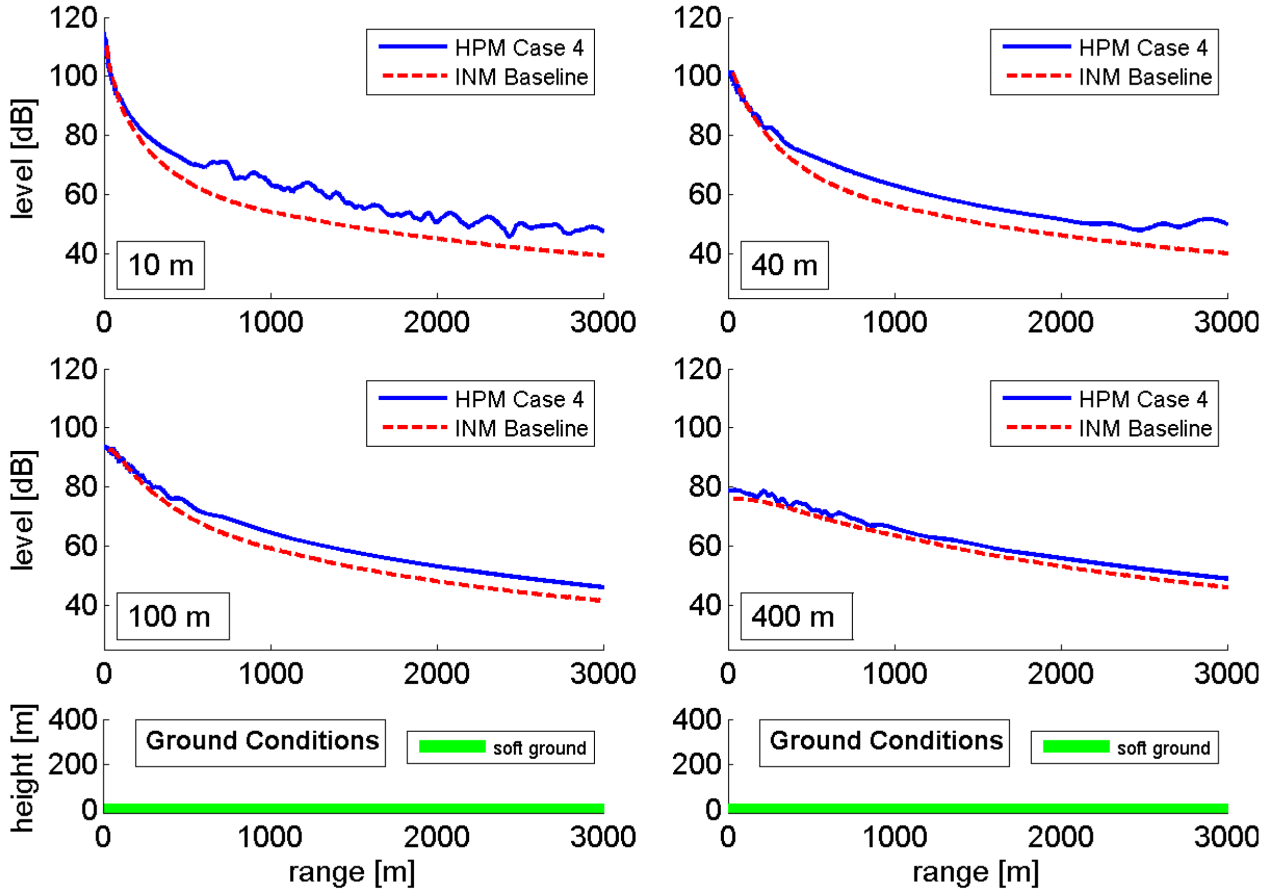

Figure 3. Case 4— Soft, flat ground and downward-refracting atmosphere. HPM and INM results are shown for each source height—10 m, 40 m, 100 m, and 400 m. A diagram of the propagation conditions is included beneath the results figures.

2.2 Case 5: Soft Ground, Hill, Homogeneous Atmosphere

Figure 4 shows the INM and HPM results for Case 5 (soft ground with a hill and a homogeneous atmosphere). The INM baseline case results are included for comparison. Again, the comparison shows good agreement between the INM and HPM at the smallest ranges, near the source. However large differences are seen in the effect of the hill.

The noted increase in level over the upslope of the hill predicted by the HPM is not seen in the INM results. In fact, the INM shows a slight decrease in level over the upslope of the hill. However, the INM does show a decrease in level after the crest of the hill, at approximately the same range as the drop predicted by the HPM. In addition, for the 100 m source, the INM, like the HPM, predicts an increase in level beyond the peak of the hill. While there is a similar line of sight blockage attenuation trend for the HPM and INM, the HPM predicts more extreme terrain effects than does the INM.

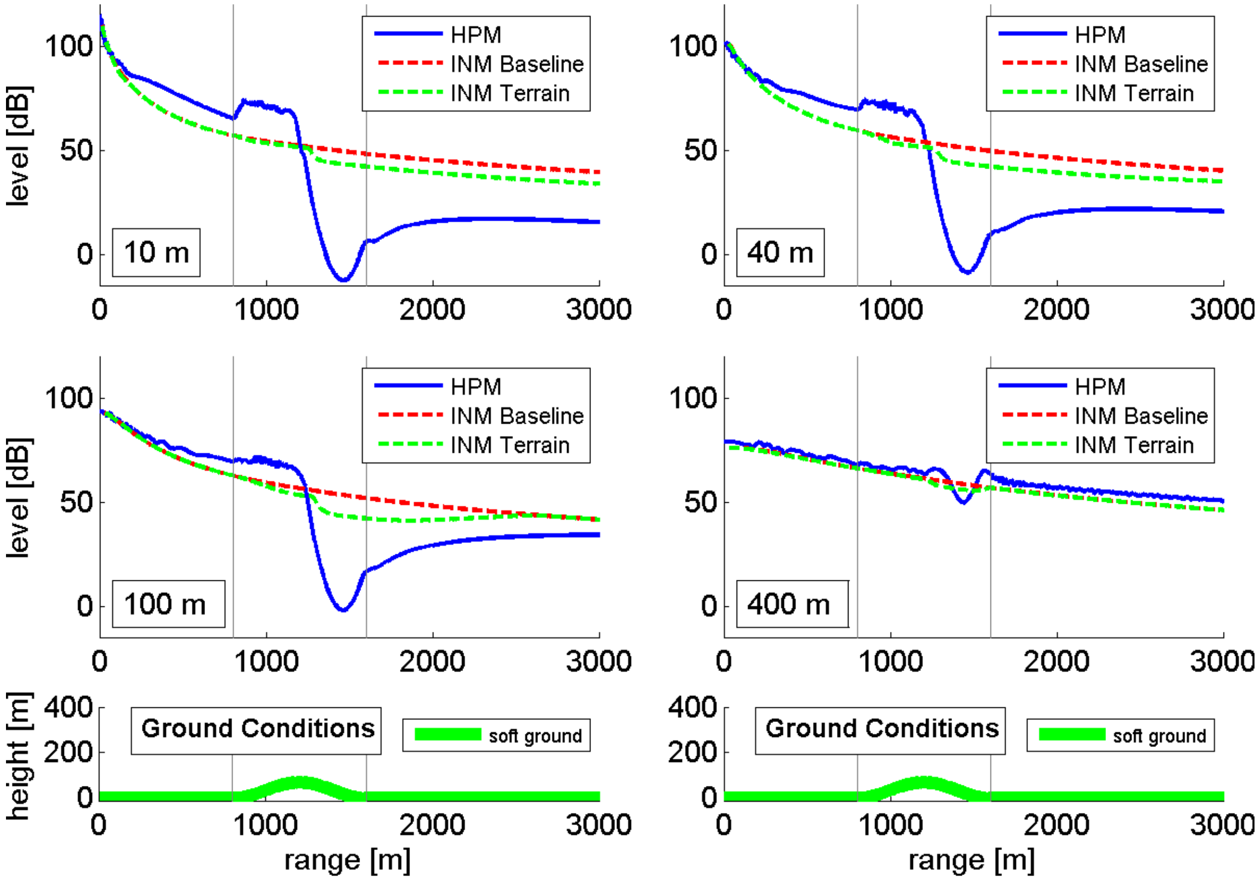

Figure 4. Case 5— Soft ground with hill terrain and a homogeneous atmosphere. HPM and INM results are shown for each source height—10 m, 40 m, 100 m, and 400 m. A diagram of the propagation conditions is included beneath the results figures.

2.3 Case 6: Soft Ground, Upward Sloping Terrain, Homogeneous Atmosphere

Figure 5 shows the INM and HPM results for Case 6 (soft ground with an upward sloping terrain feature and a homogeneous atmosphere). The INM baseline case results (with SAE-AIR-1845 atmospheric absorption) are included for comparison. Again, the comparison shows good agreement between the INM and HPM at the smallest ranges, near the source, and large differences are seen from the effect of the terrain.

The effect of the upward sloping terrain feature is smaller than that of the hill in both HPM and INM predictions. However, the effect is, again, far larger for the HPM. A slight decrease is also predicted by the INM. Because the HPM reacts more significantly to the line of sight blockage over the second region of flat terrain, HPM results drop below, or fall further below the INM predictions.

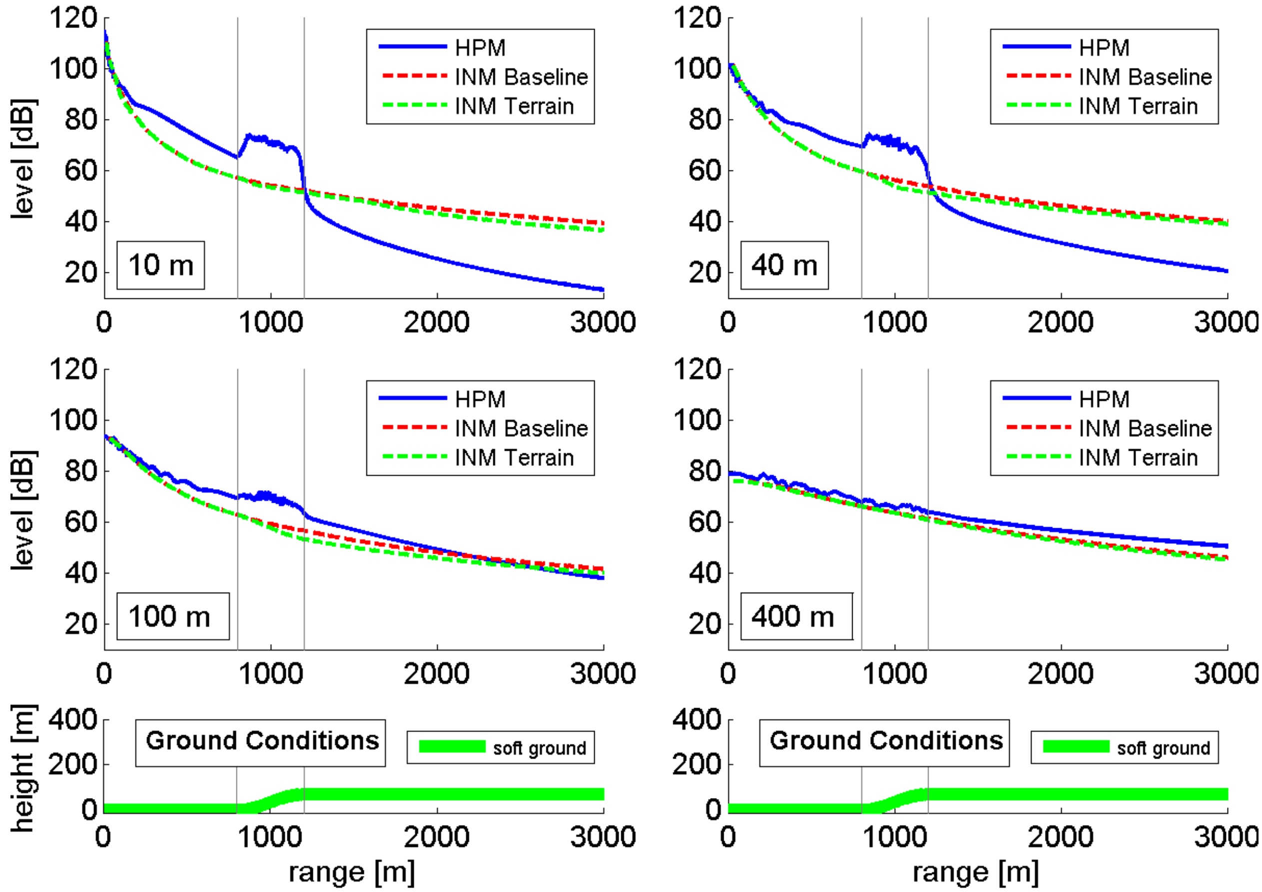

Figure 5. Case 6— Soft ground with upward sloping terrain and a homogeneous atmosphere. HPM and INM results are shown for each source height—10 m, 40 m, 100 m, and 400 m. A diagram of the propagation conditions is included beneath the results figures.

2.4 Case 7: Soft Ground, Downward Sloping Terrain, Homogeneous Atmosphere

Figure 6 shows the INM and HPM results for Case 7 (soft ground with a downward sloping terrain feature and a homogeneous atmosphere). The INM baseline case results are included for comparison. Again, the comparison shows good agreement between the INM and HPM at the smallest ranges, near the source. While large differences are also seen from the effect of the terrain, the two models do show similar trends in their results.

For the lowest three sources (10 m, 40 m, and 100 m) in both the INM and HPM, the levels decrease over the downward slope where the line of sight is first broken. Levels increase again at farther ranges in both sets of results. The notch in level is seen most clearly for the 100 m source, for which the line of sight is broken, and then, subsequently, recovered later in the range (the direct path is unobstructed for the second time starting at the 1399 m range).

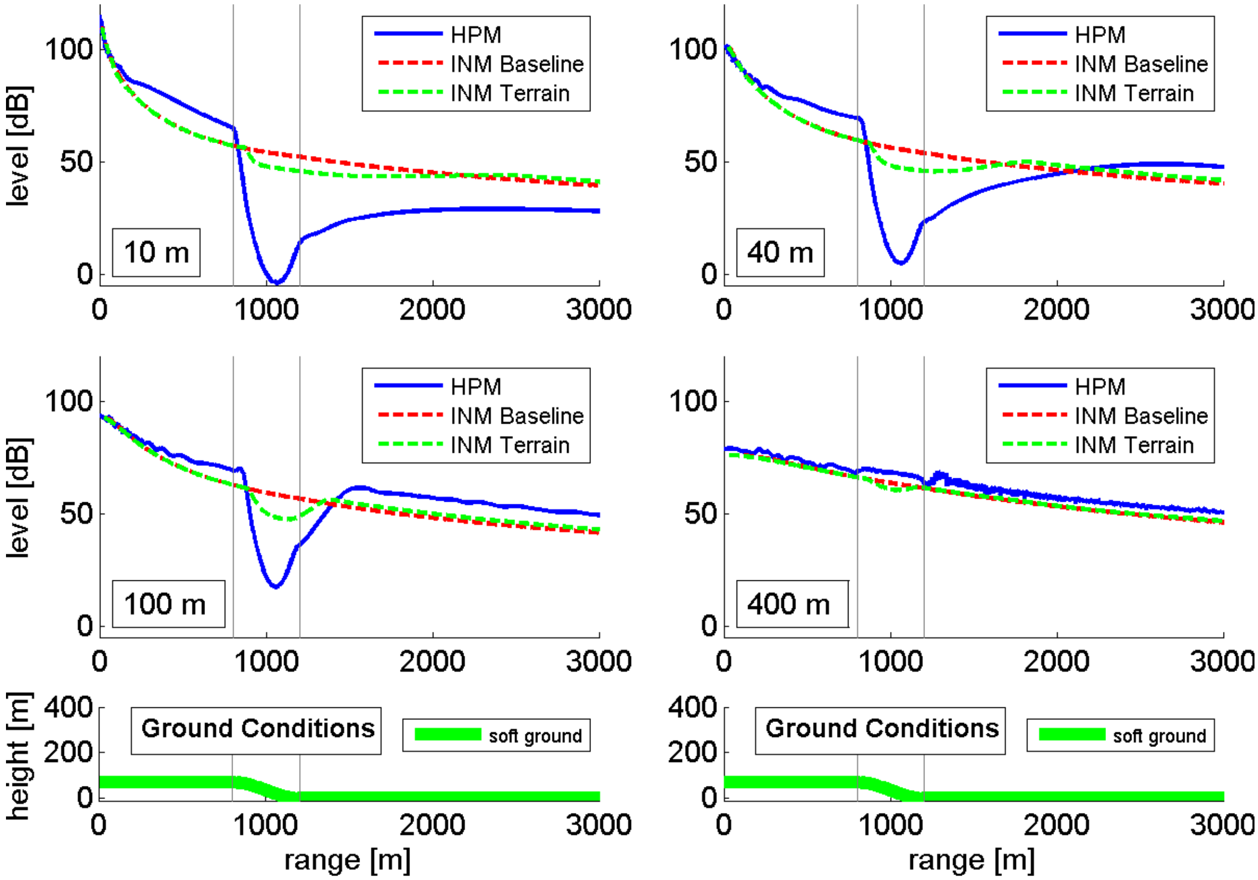

Figure 6. Case 7— Soft ground with downward sloping terrain and a homogeneous atmosphere. HPM and INM results are shown for each source height—10 m, 40 m, 100 m, and 400 m. A diagram of the propagation conditions is included beneath the results figures.

3. DISCUSSION

Significant differences were observed between INM results and those of the HPM. The larger differences in predicted levels appeared beyond the small propagation ranges, especially for lower altitude sources. Results for the highest altitude source, however, tended to show differences of only a few dB across the different test cases. The absence of lateral attenuation in the HPM may explain some of the differences observed.

At lower source altitudes, the relationship between INM and HPM results is more complex. Here are a few likely hypotheses:

1. Ground impedance: the effect of the ground at lower source altitudes is more pronounced. Unlike the HPM, the INM does not allow the specification of a ground flow resistivity value other than the default soft ground. Hence the INM may reflect a different flow resistivity than that used by the HPM in this study.
2. Aircraft measurements are performed for overflights ranging from 500 to 1,000 ft (152 to 305 m) above ground level[7] and are extrapolated for lower source altitudes. Further validation could be conducted to ensure this extrapolation is not the source of disagreement between the INM and HPM for the lower altitude, 10 m and 40 m sources.
3. Airplane shielding effects and other engine/aircraft installation effects incorporated in the lateral attenuation adjustment are not included in the HPM and may account for a few decibels over-prediction by the HPM. A model of these components of lateral attenuation could be added into the HPM.

The comparison between the INM and HPM confirmed that source level modeling was accurately transferred from the INM to the HPM. The sometimes large differences between the two models strongly suggest further investigation and validation against measurement data is needed. However, results show both closer agreement between the HPM and INM for the higher altitude source, and similar trends in attenuation for line of sight blockage effects. Because most events in INM studies address events above 400 m altitude, INM's accuracy may be acceptable in standard applications.

The feasibility of implementing a form of the HPM into the AEDT depends on the model's runtime and required computational effort. Unfortunately, the full version of HPM is slow and computationally expensive. Using HPM component models for propagation in place of the full model relieves computational burden to varying degrees: For example, Base Case 1 took over two days to run with the HPM and slightly under two days to run with just the FFP. In contrast, the ray model ran Base Case 1 in less than a minute. Still, the INM took only seconds to run.

4. CONCLUSIONS

HPM results for four cases—the base, hill, upward sloping terrain, and downward sloping terrain cases—were compared with INM. The HPM was found, generally, to predict higher levels than the INM, especially for the three higher altitude sources. In the comparison with HPM results for Base Case 1, which uses a homogeneous atmosphere, differences in the rates of attenuation over the propagation range are seen between the INM and HPM. However, the shape of the HPM results curve for Case 4, which represents a downward refracting atmosphere, matches the INM results more closely, though the HPM still predicts higher levels.

Additionally, in all three terrain cases, the HPM predicts more extreme terrain effects than does the INM. Smaller line of sight blockage attenuations would be expected under downward refracting, as opposed to homogeneous atmosphere conditions. However, the three HPM terrain cases considered were not run with a refractive atmosphere and, therefore, further comparisons under different atmospheric conditions were not possible. The higher altitude, 400 m source, for which there is no line of sight blockage, showed the closest comparisons between the two models in all cases, with differences of only a few decibels.

The accuracy of the HPM for complicated propagation conditions comes at a steep computational cost. HPM runtimes are on the order of days, while INM's are on the order of seconds.

5. FUTURE WORK

Refraction-scattering effects are accounted for in the INM's lateral attenuation algorithms, which are currently based on SAE-AIR-5662. That document represented a significant advancement over SAE-AIR-1751. However, in order to maintain consistency with the original document for certain conditions and be applicable to a variety of conditions, the refraction-scattering effects component of the lateral attenuation adjustment implicitly assumes certain characteristics of the atmosphere that are not explicitly defined[†]. While INM does not currently account for varied refractive properties of the atmosphere, the appropriate set of atmospheric conditions for HPM input would closely reproduce the lateral attenuation adjustment's role in shaping the INM noise predictions. Comparing INM with HPM under the same atmospheric conditions would offer a baseline of differences between the models. After these core differences are known, the errors caused by actual versus assumed atmospheric propagation conditions can be assessed and the differences in terrain effects can be isolated. For future comparisons with INM, the assumptions about atmospheric conditions should be resolved.

Many significant differences between the INM and the HPM were found in the comparisons discussed in this report. However, long runtimes make implementing the HPM in a widely used model impractical. In the near term, an advanced ray model, capable of including terrain, ground transitions, and atmospheric effects may provide a suitable compromise between accuracy and runtime. To further increase accuracy, the HPM could be substituted in place of the ray model at low frequencies, for which ray model assumptions do not hold and the HPM runs more quickly. Once an advanced ray model is developed, comparisons can be made with the HPM to determine the appropriate transition frequency for such an extension to the model.

[†] The lateral attenuation adjustment in AEDT and INM is an empirical adjustment that was developed over a range of atmospheric conditions. These average conditions somewhat favor downward refracting atmospheres.

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