

Modeling anthropogenic noise propagation using the Sound Mapping Tools ArcGIS toolbox



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ABSTRACT

We introduce the open-source Sound Mapping Tools (SMT, implemented in ArcGIS with the Spatial Analyst extension) for use in terrestrial outdoor sound propagation modeling. SMT includes three sound propagation models: an updated version of SPreAD-GIS, based on the System for Prediction of Acoustic Detectability model; NMSIMGIS, a GIS implementation of the Noise Model Simulation (NMSim) algorithms; and an implementation of an international outdoor sound propagation standard, ISO 9613–2. SMT produces spatially-explicit predictions of sound pressure levels from one or more sound sources, facilitating the assessment of noise effects from sources such as motorized recreation, energy development, and road traffic. Model results can be weighted to represent variable acoustic sensitivity or compared to ambient sound pressure levels. SMT provides a user-friendly approach to produce sound level predictions across variable landscapes, with applications for environmental, behavioral, population, and community ecology studies and for planning and management of human land use and infrastructure.

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Software availability

Name of software: Sound Mapping Tools (SMT)

Developer: Alexander Keyel

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Availability: free at <http://purl.oclc.org/soundmappingtools>

Available since: October 2016

Software required: ArcGIS 10.3–10.5 with the Spatial Analyst extension and Python

Program language (size): Python (1.5 MB)

1. Introduction

With increasing recognition of the important role of sound in ecological processes (Dumyahn and Pijanowski, 2011) and the impacts of noise on human health (Stansfeld and Matheson, 2003), wildlife populations (Shannon et al., 2015), and ecosystem services (Francis et al., 2012), approaches to characterize soundscapes (i.e., acoustic environments) and model sound propagation (i.e., how sound spreads from its source across the landscape) are needed.

Knowledge of sound sources and levels in a soundscape may inform ecological studies of intra- and inter-specific communication, behavior, population dynamics, and community ecology, as well as effects of noise pollution (i.e., unwanted sounds) on species, ecosystems, and human communities.

Here, we introduce Sound Mapping Tools (SMT), a toolbox designed to support environmental planning and management to assess, minimize, or mitigate noise impacts. SMT uses the physics of sound propagation to make quantitative sound level predictions for known sound sources. SMT is an open-source toolbox, which enables the toolbox to be adapted to users' specific needs, and facilitates the incorporation of cutting-edge sound modeling approaches. SMT is implemented in proprietary ArcGIS software (ESRI, Redlands, CA) to take advantage of a large, well-trained user-base, and to incorporate ArcGIS's well-developed and well-documented spatial analysis tools.

2. Sound propagation model descriptions

The use of three established sound propagation models provides SMT with a strong foundation. SMT includes implementations of SPreAD-GIS, developed by the USDA Forest Service for managing noise from outdoor recreation (Harrison et al., 1980; Reed et al.,

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2012), Noise Model Simulation (Ikkelheimer and Plotkin, 2005), recommended for use by the U.S. National Park Service (Sunder, 2003; but see Zusman, 2005), and ISO 9613–2, the international standard for outdoor sound propagation. SPreAD-GIS has been used for diverse applications, including modeling noise propagation from oil and gas compressors (Barber et al., 2011) and selecting field sites for a scientific study of highway noise effects on birds (Grade and Sieving, 2016). Noise Model Simulation was created in the 1990's in order to compare simulation results to the results of an integrated model (NOISEMAP, Plotkin, 2001) and has been applied to a variety of environmental analyses (Plotkin, 2001), such as planning air tours in the Grand Canyon (Miller et al., 2003) and the winter management plan for Yellowstone National Park (Jacobson, 2013). ISO 9613–2, as an international standard, has been widely applied for questions pertaining to outdoor acoustics (e.g., Schomer, 2003).

All three models produce spatially-explicit maps of predicted sound levels by starting with a source level and then computing loss (or gain) through a series of mechanistic modules (Fig. 1): spherical spreading loss, atmospheric absorption, vegetation and ground effects, wind effects (SPreAD-GIS only), and loss due to terrain barriers (Fig. 1). Briefly, spherical spreading loss is the reduction in sound pressure levels with distance due to the diffusion of sound energy as it spreads out over an increasing area, atmospheric absorption is the absorption of sound energy by N₂ and

O₂ molecules in the atmosphere, wind effects are loss due to refraction (i.e., bending) of sound waves by the wind, foliage and ground cover effects are the sound loss (or gain) due to interactions with the ground, and barrier effects are sound levels lost due to reflection or obstruction by a major terrain barrier (see e.g., review by Embleton, 1996; ISO, 1996).

Spherical spreading loss and atmospheric absorption for all three models follow ISO 9613–2. In contrast, ground, terrain, and wind effects differ substantially between all three models. In SPreAD-GIS, ground effects are vegetation-dependent based on tabulated values provided by Harrison et al. (1980), whereas terrain effects are based on the height and distance to the barrier. In contrast, ground effects in NMSIMGIS depend on the estimated hardness of the ground and are calculated together with barrier effects, using Rasmussen algorithms (Rasmussen, 1984). ISO 9613–2 uses the hardness of the ground, distance to a barrier, and height of the barrier to calculate ground and barrier effects. Finally, SPreAD-GIS includes wind effects based on wind direction, the direction from the source to the receiver, and the general seasonal conditions (e.g., clear, windy summer day), whereas NMSIMGIS omits wind effects and the meteorological correction for ISO 9613–2 has not yet been implemented in SMT.

The models produce instantaneous estimates of sound pressure levels and include options for summing across multiple sound sources and multiple frequencies, and for weighting frequency band results. Sound pressure levels can be summarized for particular areas, or sound pressure levels can be combined with background sound levels to compute audibility (per ISO 389–7). Other possible output metrics include maximum sound pressure levels and time-averaged sound pressure levels.

3. Example: noise from natural gas extraction

We demonstrated the application of SMT for assessing sound pressure levels associated with an illustrative example for natural gas extraction in the Piceance Basin, CO, USA (39.75° N–40.0° N, 108.5° W – 108.0° W). As sound from natural gas extraction may be detrimental to wild animals (Francis et al., 2011), hereafter we refer to the sound pressure levels for this example as noise levels. In the first example, we compared the expected noise levels from drilling at two hypothetical new well sites (Fig. 2, Fig. 3, Table 1, Appendix S1, Appendix S2). In the second example, we evaluated how model run time changed as a function of analysis cell size (resolution) and/or analysis extent for an existing well site (Table 2). SMT was run using the graphical user interface in ArcGIS (Example 1, Appendix S2) and using a Python editor (Example 2, Appendix S3).

We assembled the required data sets to run SMT to evaluate anthropogenic noise impacts from drilling a natural gas well, (Table 1). We used National Elevation Data (USGS, 2015), LANDFIRE land cover (LANDFIRE, 2012), weather data extracted from the National Oceanic and Atmospheric Administration (NOAA, 2015) and field-measured noise level data of a natural gas well (Appendix S1, E. Brown, pers. comm.). We selected the SPreAD-GIS model for demonstration purposes; however, any of the three models could have been used to produce spatial predictions of noise levels (results will vary). We summarized modeled noise levels as A-weighted noise levels, which can be converted to a variety of other metrics of interest (McKenna et al., 2016). Further, noise levels can be displayed with 1/3 octave band resolution, and the individual components that lead to sound loss can be examined separately. The first example demonstrated the toolbox's value for evaluating alternative management scenarios, as siting the well in location 1 would raise noise levels over a much larger area than in location 2 (198 and 68 ha over 25 dBA, respectively, Fig. 3).

The second example demonstrated that all three models could

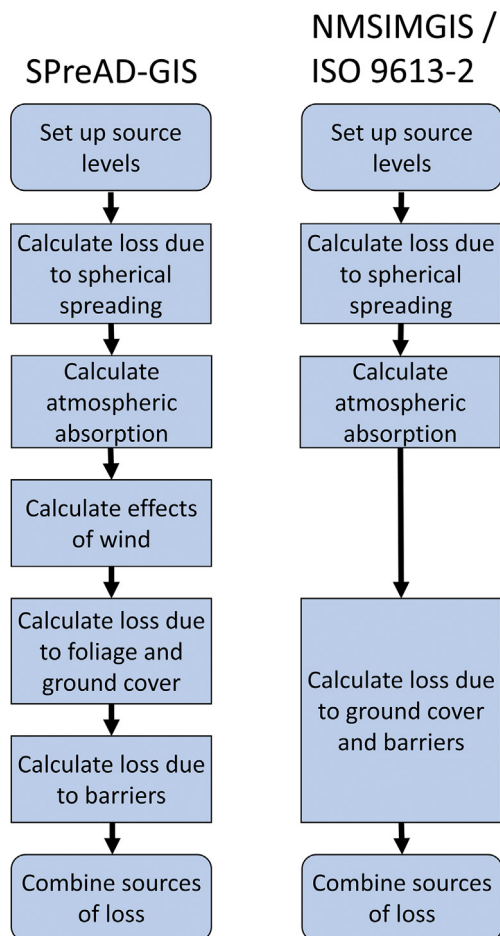


Fig. 1. Comparison of factors included in propagation loss calculations. SPreAD-GIS, NMSIMGIS and ISO 9613–2 start with source levels, calculate loss due to a variety of factors, and then combine those total losses to get a final estimate of sound propagation loss.

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