Communication

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Synchronized acoustic and atmospheric measurement system for characterization of atmospheric sound propagation

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Abstract: The aim of the paper is to describe a portable, modular, and scaleable system for measuring concurrent acoustic transmission loss and atmospheric characteristics. This system has been developed specifically to inform an effort to improve the ability to implement high fidelity numerical predictions of acoustic transmission loss, particularly in acoustically complex outdoor ranges, such as those that occur in coastal areas. Such a system has broad possible applicability in many outdoor atmospheric acoustic monitoring scenarios.

Keywords: atmospheric acoustics, transmission loss, littoral zone, meteorological mapping, wind profiling

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1 Background and motivation

The analytic study of sound propagation in the atmosphere can be associated with specific historic factors or technologies. Perhaps as soon as people began living in cities, community noise became an issue. The *Epic of Gilgamesh* from about 4000 BCE ascribes blame for a great storm and flood intended to destroy all of mankind because of noise that disturbed the Gods. Julius Caesar enacted a law that banned wheeled traffic for most of the day from inside the Roman Forum because of noise. In the later part of the nineteenth century Tyndall studied sound in coastal environments for the safety of ships near shore. In his era, lighthouse beckons were often supplemented by loud fog horns in regions inclined to fog. In 1930 Harlean James published *City Noise*, a study of the acoustic environment in New York City which had an established noise problem by that time. The next impetus for the study of outdoor sound occurred with the rise of jets. A summary of these and other milestones is given in the introduction of a review paper by Embleton [1].

Over the millennia, these and many other social forces have motivated scholars to study outdoor sound propagation. Today, highway and construction noise, noise from offshore structure including wind turbines and boats are regulated in many jurisdictions and noise generation can be an important part of the permitting portion of large infrastructure projects such as industrial facilities, highways, and airports.

Existing modeling approaches for the transmission of sound have limitations that result from the complexity of the environment. A typical starting point for predicting sound pressure levels (SPL) along an acoustic travel path is the well-known spreading loss which accounts for 6 dB per doubling of distance away from a source that is small relative to wavelength or 3 dB per doubling of distance away from a source that extends along a line. Additional and more interesting mechanisms that effect changing SPL of a propagating sound include refraction that can be caused by temperature and wind speed gradients in the atmosphere, turbulence in the atmosphere, as well as the precise nature of the ground cover.

In most cases, atmospheric conditions such as temperature, wind speed, and humidity vary with height above the ground and those vertical property profiles may also vary with propagation range. This work presents a comprehensive measurement system that captures concurrent acoustic and atmospheric parameters with the purpose of informing improvements in the numerical modeling of atmospheric acoustic propagation.

Some of the foundational work on sound propagation outdoors over both land and sea includes several fine texts [2, 4, 5]. One of the major limitations of modeling sound propagation is the assumption of homogeneous at-

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mospheric conditions along the range, even when the range extends over multiple kilometers. The assumption of homogeneous atmosphere has persisted in part due to the difficulty of measuring such meteorological conditions. Efforts have been made to include inhomogeneity by way of turbulences [2]. However, at present, the literature is lacking robust validation for any modeling approach. A simple demonstration of this need can be provided by the following example. Figure 1 compares two simulations of excess attentuation (ΔL) with range. One case employs the same vertical sound speed profile along the entire range, while the other uses a simple case of two different wind speed profiles. In the homogenous case, the wind speed at 10 m elevation is assumed to be +10 m/s with a standard logarithmic profile, and in the inhomogeneous case, the wind speed at 10 m elevation is changed to +1 m/s with a standard logarithmic profile for the range of 50 to 100 m. In this example, the discrepancy of 2 dB over only 50 m is an indicator of how profound the differences in prediction might be. In reality, the wind speed profiles are complex both along the range and vertically. This work presents a measurement system intended to couple detailed wind profile measurements with concurrent acoustic transmission loss measurements to alleviate this lack of information and oversimplification in numerical modeling efforts.

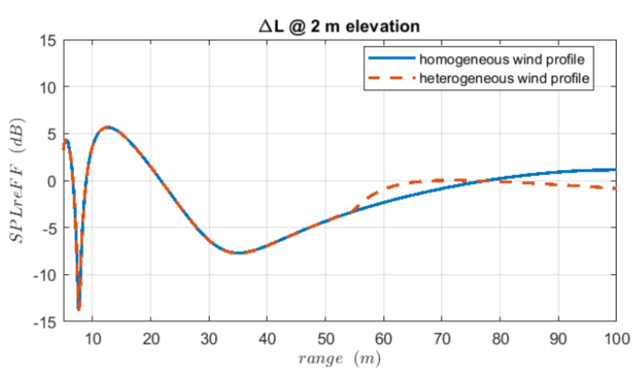

Figure 1: Excess attenuation model results for homogeneous and inhomogeneous wind speed profiles along a propagation range.

measurements with a single source and up to four independent receiver arrays. Each receiver array, as in Figure 2 consists of a 7 m portable mast with microphones configurable at 0.5 or 1 m spacing, depending on the desired study parameters. Figure 3 is a schematic representation of the measurement configuration including the acoustic source (green), the portable 7 m masts (black), audio recorders and microphones (purple), GPS synchronization units (blue), and weather station and ultrasonic anemometers (red) and the Doppler scanning LIDAR (magenta).

Figure 2: Portable mast with microphone array and associated weather station.

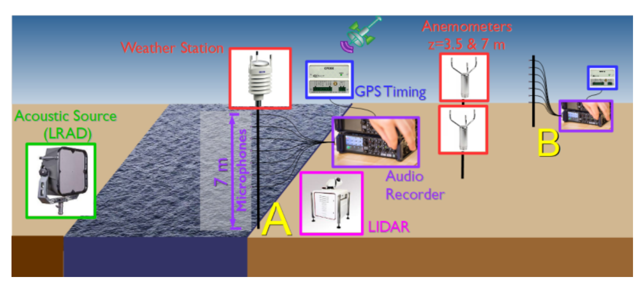

Figure 3: Schematic of measurement system components in a sample configuration.

2 Measurement approach

2.1 Acoustic transmission loss measurements

This section details the components and approach used to measure the acoustic transmission loss portion of the data stream. Typically, the studies are pitch-catch style

2.1.1 Audio recorder and synchronization

The microphones used for the array are Samson C02 condenser microphones (Samson Technologies, Hicksville, NY). Microphones are installed in the array nominally in the propagation direction and parallel to the ground. The microphones are connected to 8-channel audio recorders (Zoom

Model F8 Digital Audio Recorder, Zoom Corporation, Tokyo, Japan). The Zoom F8, designed for the film industry, accepts SMPTE (Society of Motion Picture and Television Engineers) time code signals. A MasterClock GPS500 (Masterclock, Inc, St. Charles, MO) is a GPS based time code source that outputs a SMPTE signal. A GPS500 unit is connected to each Zoom F8 recorder. Such time code information ensures that measurements made with different modules are synchronized, regardless of the distance between the modules. An important feature of this system is that the modules are *not* connected to each other by cable, allowing placement of the arrays in arbitrary configurations separated by arbitrarily long distances. Specific information about the pulse diversity approach employed and post-processing of the acoustic data is included in a prior work by the authors [3].

2.1.2 Acoustic source

The acoustic source used in this system is a portable acoustic hailing device (LRAD 500X-RE, Genasys, Inc., San Diego, CA). The system has a nominal peak continuous source level of 149dB with a 30° beam width at 1 kHz.

2.2 Meteorological measurements

In addition to more traditional and commonly available meteorological measurement devices, the centerpiece of this system is a custom field-deployable scanning Doppler pulsed LIDAR (Windcube Scan 100s, Vaisala, Vantaa, Finland) to provide high spatial and temporal resolution wind speed measurements. The LIDAR system is custom-mounted on a trailer with a generator system (Figure 4) such that measurements can be made at any desired location. The system is capable of several scan geometries including DBS (Doppler Beam Swinging), PPI (Plan Position Indicator), RHI (Range Height Indicator) and a fixed stare in any direction. The DBS mode provides a three-dimensional reconstruction of the wind vector in a cone shaped user-defined volume; the PPI mode provide a planar distribution of radial wind velocity over a user-defined cone shaped sweep (Figure 5); the RHI mode provides a planar distribution of radial wind velocity at a particular heading over a particular range of elevations (Figure 6).

In addition to the LIDAR wind profiling, the measurement system includes two dedicated weather stations: one Davis Vantage Vue (Davis Instruments, Hayward, CA, US) and one Vaisala WXT 536 (Vaisala, Vantaa, Finland). The Vantage Vue logs weather parameters once per minute and the WXT536 logs at 1 Hz. Both weather stations record tem-

Figure 4: Windcube Scan 100s field-deployable scanning Doppler LIDAR

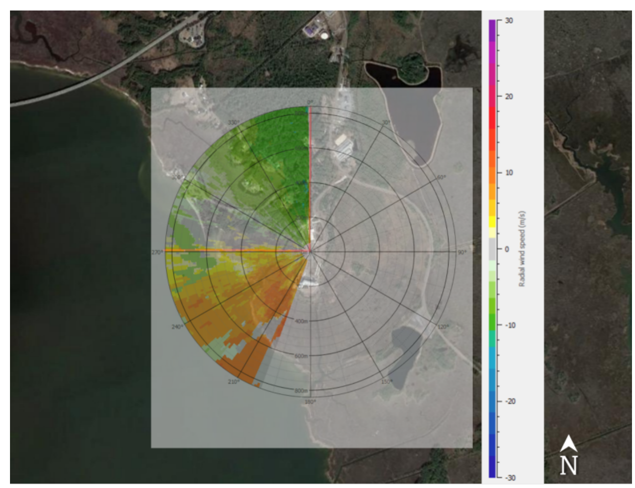

Figure 5: PPI scan with 25m range gate showing radial wind speed up to a 900 m range.

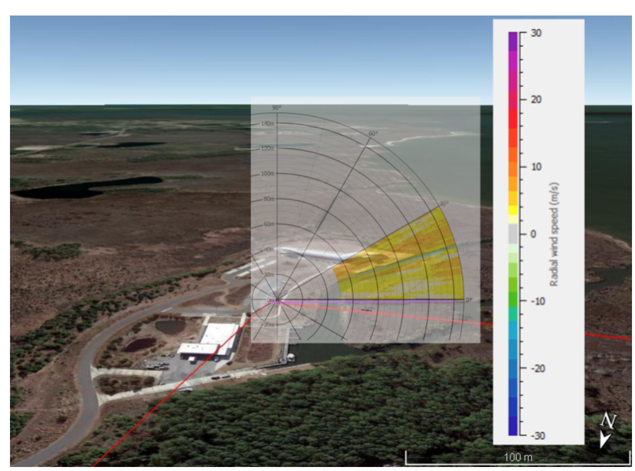

Figure 6: RHI scan with 25 m range gate showing radial wind speed up to a 30° elevation and 150 m range.

perature, atmospheric pressure, relative humidity, wind speed and direction, and are mounted atop the 7 m acoustic masts. The system also includes two dedicated 7 m masts that are each instrumented with a pair of WMT700 ultrasonic anemometers (Vaisala, Vantaa, Finland). These are positioned at elevations of 3.5 and 7 m and provide additional continuous wind speed profile information sampled at 4 Hz at two fixed locations on the measurement site.

3 System capability

In order to highlight the need for high resolution wind information, a sample measurement using a 25 m range gate is presented in Figure 5. Note the radial wind speed along the WSW heading changes direction twice (yellow to green to yellow) along a relatively short (900 m) propagation range. The synchronized acoustic measurements that will accompany the wind measurements of this type will allow validation of various modeling approaches and parameter sets. Figure 6 covers a shorter range (150 m) and elevations from 0 to 30°. Noteworthy in this example is that the velocity profile does not change in a smoothly logarithmic fashion, which is the commonly assumed vertical wind distribution.

4 Conclusions

This paper describes a measurement system that can enhance the quality of the description of an acoustic environment and provides a tool to validate numerical modeling approaches for atmospheric acoustic propagation. The advantage of implementing such a system resides in the synchronization of acoustic transmission loss data with actual concurrent meteorological conditions. This specific property allows reduction of uncertainty of sound pressure level predictions related to unknown fluctuation of wind speed along the acoustic path.

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