A PROTOTYPE ACOUSTIC BATTLEFIELD DECISION AID WITH INTERFACES TO METEOROLOGICAL DATA SOURCES AND A TARGET DATABASE

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ABSTRACT

This paper describes a prototype physics-based decision aid, called the Acoustic Battlefield Aid (ABFA), for predicting environmental effects on the performance of acoustical sensors. ABFA integrates advanced models for acoustic refraction and scattering, array signal processing, and the atmosphere into an easy-to-use graphical user interface. Available performance characterizations include probability of detection, direction-finding accuracy for isolated receiving arrays, and location-finding accuracy for networked receiving arrays. An overview is provided of the various physical models and how they operate together to characterize sensor performance. New features include an interface to the ARL Database/Automatic Target Recognition Laboratory and a Java-based capability for network access of forecasts from the Army's Integrated Meteorological System. A suite of tools has also been added to perform tasks such as creating new target descriptions from standard digitized audio files and designing sensor array layouts.

1. INTRODUCTION

Acoustical sensors will likely play a prominent role on the future battlefield, where information dominance and maneuverability will be key. Their main advantages are low cost and operational capabilities in non-line-of-sight conditions. A potential disadvantage is that their performance depends strongly on environmental conditions. Sound waves are refracted by atmospheric wind and temperature gradients, creating "hot spots", where sound pressure levels are locally elevated, as well as "shadows", where levels are locally depressed. Furthermore, random fluctuations in the received signal level and reductions in signal coherence result from interactions of the sound with turbulence and other random atmospheric motions. In this paper we describe recent enhancements to a prototype physics-based tactical decision aid, called the Acoustic Battlefield Aid (ABFA), which analyzes atmospheric refraction and turbulence effects on acoustical detection and tracking systems.

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Most new U.S. Army acoustical systems use small, ground-based beamforming arrays (footprint less than several square meters) to determine the horizontal bearing angle of sound-emitting targets. The original purpose in developing ABFA was to merge a newly developed capability at the U.S. Army Research Laboratory (ARL) for predicting the performance of such arrays (Wilson 1998a) with the best available computer models for point-to-point acoustic transmission loss, thereby laying the groundwork for innovative acoustical decision aids on the digitized battlefield of the future. Also incorporated into ABFA are statistical models for signal fluctuations and background noise, as well as micrometeorological models for estimating refractive profiles and turbulence spectra from basic surface weather observations. These four components were combined under an intuitive and flexible graphical user interface (GUI) that provides for the calculation and display of acoustic probabilities of detection, direction-finding accuracy, target location-finding accuracy, sound pressure levels, and several other sensor performance metrics.

Many details of ABFA's computational algorithms and user interface are described in a pair of ARL technical reports (Wilson 1998b; Wilson 2000a). An overview of ABFA, with applications to tracking of cruise missles, was also given at the previous IRIS meeting (Wilson et al 2000). Because of the desire to apply ABFA in a variety of scenarios and to make it simpler to use, many new capabilities have been added to ABFA during the past year. These include improvements to the underlying acoustical calculations, convenient enhancements to the GUI, and the addition of a set of powerful tools for developing new target and sensor descriptions. The latest version includes a Java-based interface for network retrieval of meteorological data sources and some useful capabilities for interfacing with the ARL/SEDD Database/ Automatic Target Recognition Laboratory.

ABFA has been developed in the MATLAB™ programming environment for several reasons, foremost among which is that MATLAB has allowed for rapid development of the program's underlying calculation routines as well as the graphical functions. Developing a tool such as ABFA in a lower-level language would have required an investment of programmer time far exceeding current resources. In addition, the ABFA MATLAB routines are easily transportable to various platforms, such as the PC-Windows environment, Apple Macintosh, and Unix workstations, with a trivial installation procedure. The new MATLAB compiler and graphics library should enable creation of standalone executables.

The six following sections highlight various aspects of ABFA and its operation. Section 2 provides an overview of the basic program interface and functions. Section 3 describes the basic calculation methods for modeling acoustic sensor performance. Two new tools, AWAUI and RAD, that aid in the creation of new source and receiver descriptions are described in Section 4. Interfaces to atmospheric data sources and target signature database are described in Sections 5 and 6, respectively. Lastly, in Section 7, performance of a network of acoustical sensors operating in a desert environment is modeled.

2. ABFA OVERVIEW

An example of the main ABFA window as it appears when the program is first started is shown in Figure 1. The terrain elevation is displayed as a colored mesh. Slider bars at the top of the display allow the terrain view to be adjusted in azimuth and elevation. New view angles can also be entered directly into the text boxes above the sliders. Acoustic sources (targets) are indicated by x's, receivers (sensors) by o's, and surface weather stations by Δ's. Pull-down menus along the top of the window allow the user to perform various functions, as explained in the following:

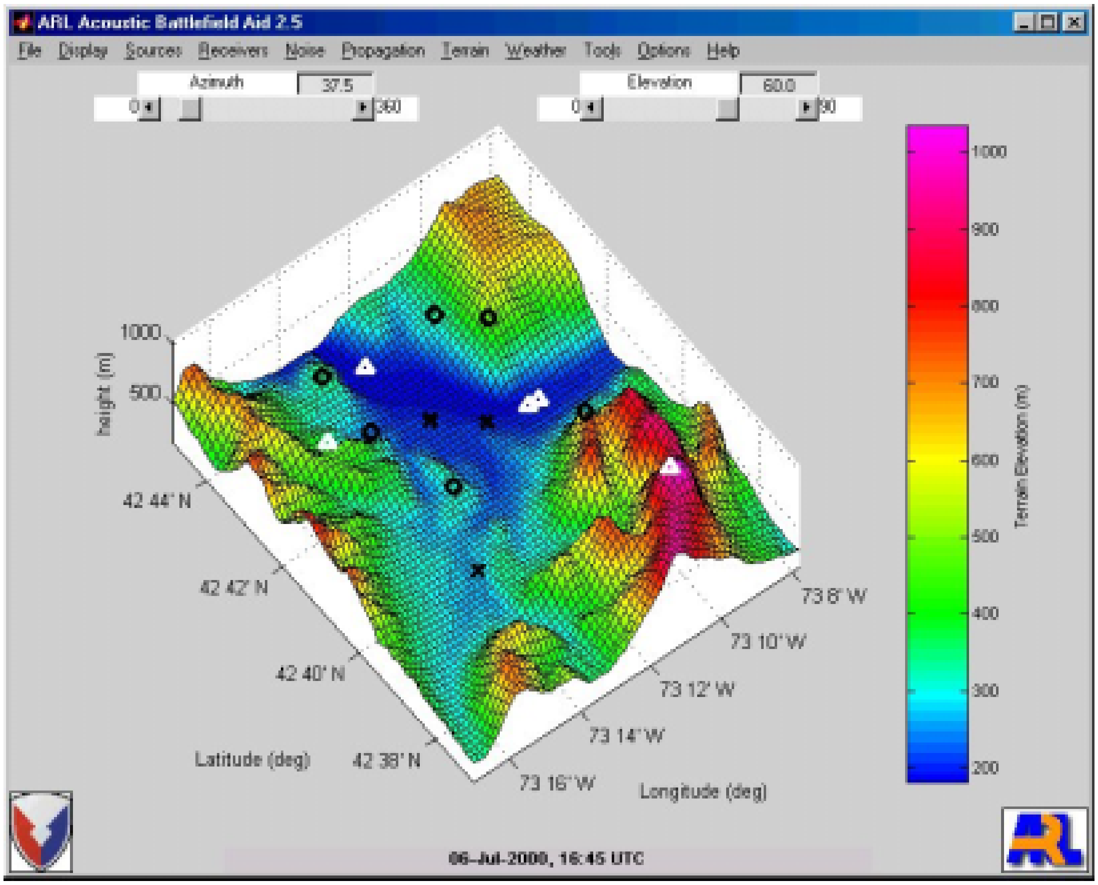

Figure 1. Main ABFA display, showing terrain elevation, source locations (X's), receiver locations (O's), and available surface weather stations (Δ's).

- **File:** Save/load parameter files for the sources and their properties, the receivers and their properties, the propagation model settings, the terrain, and the weather. Print the display. Save calculations to text and graphic files. Quit or restart the program.

- **Display:** Choose the current display quantity (terrain elevation or one of ABFA's calculations). Set the format of the display to 3-D mesh with color overlay, 2-D overhead view with color overlay on a map background, or 2-D overhead view with contours on a map background. Set the colors and scale of the display.

- **Sources:** Add new sources to the simulation. The available classes of sources are listed on the pull-down menu. These classes include idealized harmonic sources, wheeled vehicles, tracked vehicles, fixed-wing aircraft, and rotary-wing aircraft, among others. Under each class are submenus listing the specific types that are available. For example, in the current version under "Armored, Tracked", one finds "BMP," "M1," "M60," and "T72," among others. A source description consists of several fields describing the source's position, speed, spectrum, radiation pattern, and other attributes. When the user adds a new source from the pull-down menu or displays the properties of an existing one, ABFA creates a dialog box showing the attributes of the source available for editing.

- **Receivers:** Add new receivers to the simulation. This menu works in the same way as the Sources menu. Available receiver types include idealized point sensors and arrays in various geometries. (Arbitrary sensor layouts can be created using the Receiver Array Designer, discussed in Section 5.)

- **Noise:** Set and display the spectrum for the background noise. Various pre-defined noise backgrounds, such as "Pink," "White," "Rural or Forest," and "Urban" are available. The user can also create his/her own noise background, customizing the spectrum as well as the variability. A formula for estimating wind noise (turbulent pressure fluctuations that mask the sound) can also be invoked.

- **Propagation:** Change the settings of the acoustic propagation model for signal transmission loss, saturation, and coherence (e.g., turn on/off ground effects, weather effects, sound absorption, and terrain shadowing).

- **Terrain:** Change the dimensions of the coordinate grid, the latitude and longitude of the grid origin, set new terrain elevations and ground properties, and add barriers (e.g., buildings) to the terrain. There are two main methods for setting the terrain elevation. The first is to generate a synthetic random terrain. Both a single-scale (Gaussian) and a multiscale (fractal) option are available. For these synthetic terrains, the user specifies a standard deviation for the height and an outer length scale. The second method is to load actual elevations from a DTED (Digital Terrain and Elevation Data) CD-ROM, available through the National Imagery and Mapping Agency. ABFA's routine for reading DTED automatically finds the required files on the CD-ROM based on the coordinate origin latitude and longitude. The routine even works properly across DTED grid cells, prompting the user to load a new CD when necessary.

  In addition to the terrain elevation data, ABFA's calculations require information on the acoustical, aerodynamic, and optical properties of the ground. These properties can be set to reasonable default values for a dozen different types of common ground surfaces such as grass, sand, and snow. Or, the user can customize a ground surface with an interactive dialog box. The acoustical ground properties are the static flow resistivity, the porosity (void fraction), the tortuosity, and a geometrical shape factor. These are used to calculate the acoustic impedance and bulk wave number based on a four-parameter relaxational porous ground model (Attenborough 1985; Wilson 1997). The aerodynamic properties of the ground (roughness height and zero-plane displacement height) are needed to calculate the atmospheric wind and temperature profiles. If the surface-energy balance model is used to estimate the profiles, optical ground properties (surface albedo and emissivity) are also needed.

- **Weather:** Load and plot the vertical profiles for wind and temperature, and set the turbulence spectral models. Six options for specifying the profiles are available. "Pre-Defined Refractive Profiles" allows the user to choose among several benchmark cases. "Pre-Defined Meteorological Cases" allows the user to choose among several realistic meteorological conditions that are specified in lay terms, such as "Mostly Sunny and Windy" and "Overcast and Calm." "Enter Surface Data" brings up a dialog box that initiates estimation of the near-surface vertical profiles from standard surface observations. This is accomplished with a surface-energy balance model based on empirical equations originally developed by Burridge and Gadd, which are described in Stull's book (Stull 1988). "Enter Scaling Parameters," an option mainly of interest to users with training in micrometeorology, allows direct input of the atmospheric surface-layer similarity scaling parameters. The remaining two options, "Load Surface Weather Message" and "Load Vertical Profiles," initiate internet retrieval of atmospheric observations and forecasts. These options are discussed in more detail later in this paper.

  Regarding the turbulence spectral models, there are actually three separate, additive contributions: one for buoyantly produced (large-scale) velocity fluctuations, a second for shear-produced (small-scale) velocity fluctuations, and a third for temperature fluctuations. (The temperature field has no large-scale component in the surface layer.) For most purposes these models should all be set to "Isotropic von Karman," to invoke ABFA's realistic suite of turbulence models.

- **Tools:** Access the tools for creating new source, receiver, and background noise descriptions. (These will be discussed in more detail in the next section.) Create and play back movies of sensor coverage. Generate plots of the signal and noise spectra, and frequency dependence of the currently displayed quantity.

- **Options:** Select the Earth-coordinate system to longitude and latitude or to UTM (Universal Transverse Mercator) coordinates. Choose relative (to southwest corner of domain) or absolute coordinates for the display. Select the method for specifying the time (Universal Coordinated Time (UTC), local standard time, or daylight savings time). Enable/disable automatic loading and saving of run-time parameters.

- **Help:** Display help for the different types of calculations, mouse actions, and all ABFA menus. Also run the Getting Started Guide, a sequence of informational windows that guide the user through the initial process of setting up an analysis.

A new display (calculation) is invoked by right-clicking on the terrain elevation mesh. A pop-up menu showing the available calculations then appears. The displays are grouped into three classes: terrain elevation, derived calculations, and basic transmission calculations. The basic transmission calculations (transmission loss, signal saturation, and signal coherence) are the core capability of ABFA, modeling the environmental effect on a sound wave as it propagates from a source to a receiver. These calculations will be discussed in more detail later in this paper. The available derived calculations (detection probability, direction-finding accuracy, location-finding accuracy, velocity-finding accuracy, signal-to-noise ratio (SNR), and sound pressure level) invoke repeated use of the basic transmission calculations and, except for sound pressure level, require the modeled noise background spectrum. Direction-, location-, and velocity-finding accuracy all refer to the root-mean-square error in the horizontal source plane.

Most of the calculations, both basic and derived, can be run with either a fixed source or receiver location. For example, if a detection probability calculation is run for a fixed source location, the display color mapping represents the probability that a receiver positioned at the mesh grid point will detect a source. Some of the derived calculations inherently apply to networks of receivers. In particular, location-finding accuracy and velocity-finding accuracy reflect the ability of a network (each receiver node being a sensor array) to resolve the location and velocity of a source. Other calculations (such as direction-finding accuracy, SNR, and transmission loss) inherently apply to only a single node. The detection probability calculation is unique in that it applies to either a single node or a network. When run for a network, the display reflects the probability of *any* of the nodes in the network detecting the source.

The properties of sources and receivers can be viewed and changed by right-clicking on them. A pop-up menu appears, from which the user can select "Move," "Copy," "Delete," or "Properties." The move and copy operations are done graphically, by clicking on the desired new location. "Properties" displays a dialog box showing the editable attributes of the source or receiver. A display of the spectrum of the source can be launched from this dialog box, with the AWAUI tool described in the next section. Similarly, the layout of a receiver array can be viewed and edited with the RAD tool.

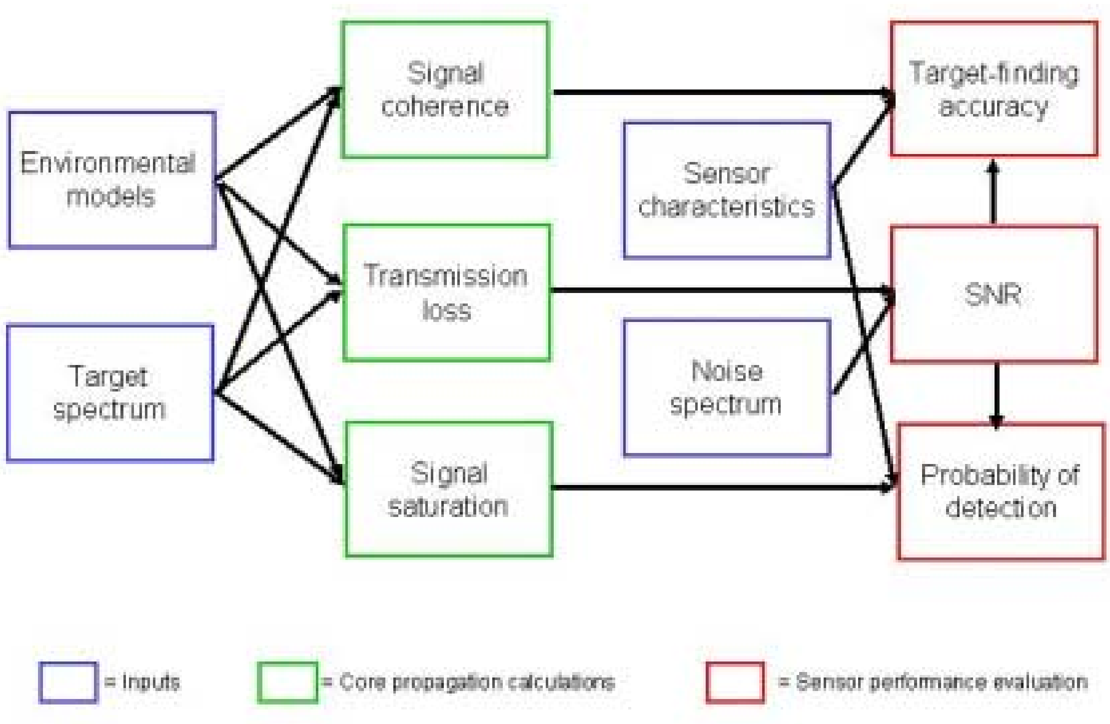

Figure 2. Calculation flowchart for ABFA.

3. CALCULATION METHODS

As mentioned in the previous section, ABFA's algorithms for predicting detection probability, bearing accuracy, and other quantities of practical interest depend on combinations of three basic transmission calculations: (1) the transmission loss (change in mean signal level as the sound energy propagates from source to receiver); (2) the mutual coherence of signals between sensors in an array; and (3) the degree of signal saturation (fading). ABFA performs each of these three calculations separately. The latter two are calculated using line-of-sight theory for wave propagation through turbulence. Although this procedure is not always valid (particularly in refractive shadow regions), the state-of-the-art in numerical propagation modeling is insufficient for treating all three phenomena in a unified, non-line-of-sight manner. The basic internal flowchart for ABFA calculations is shown in Figure 2. This sequence of steps, although complicated, is completely transparent to users.

Five methods for calculating transmission loss are available: simple spreading, the impedance plane, the fast-field program (FFP), the Crank-Nicholson parabolic equation (CNPE), and the Green's function parabolic equation (GFPE). Simple spreading is computationally the fastest option, but also has the lowest fidelity. It assumes the sound energy decays in proportion to $1/r^2$, with r being the propagation distance. This method is useful when quick results are needed.

The impedance plane calculation is more accurate than the simple spreading model in that it incorporates interactions of the sound wave with the ground (Chien and Soroka 1975). It is quite fast, the main drawback being that atmospheric effects (refraction by wind and temperature gradients) are not included.

The FFP (West et al 1991) directly solves the acoustic wave equation using wave number domain integration. Unlike basic ray-tracing methods, the FFP does not depend on high-frequency approximations that are often poor in relevant Army scenarios. The FFP accounts for refraction by gradients, diffraction into shadow regions, and ground interactions. Unfortunately it is very computationally intensive.

Like the FFP, the CNPE solution does not involve high-frequency approximations. A parabolic (forward propagating) approximation to the full wave equation is solved by a finite-differencing method. The CNPE accounts for most of the same propagation effects as the FFP and is also rather time consuming. The parabolic equation implemented in ABFA is a standard wide-angle Crank-Nicholson algorithm (West et al 1992).

The GFPE (Gilbert and Di 1993) is a recent addition to ABFA. This method is generally 10 to 1000 times faster than the CNPE yet appears to give very good results.

The basic line-of-sight theory for signal saturation and coherence is described by Ostashev (1997). Hence I give only a brief summary here. *Saturation* refers to randomization of signal amplitude and phase resulting from wave scattering. An unsaturated signal has a constant signal amplitude and phase, whereas a fully saturated one has uniformly distributed random phase and amplitude fluctuations that satisfy a Rayleigh probability distribution. This statistical behavior of the signal affects probability of detection and other aspects of sensor performance.

The line-of-sight saturation model used by ABFA assumes that the deterministic part of the signal decays exponentially with increasing source-receiver separation. The decay exponent depends on the acoustic frequency, variance, and integral length scale of the acoustic index-of-refraction fluctuations.

The coherence (complex cross correlation between two sensors at a fixed frequency) also decays exponentially with increasing source-receiver separation. However, the decay exponent depends on the complete spectrum of the turbulence. As one might expect, the exponent increases with increasing sensor separation. ABFA uses recently developed models for the three-dimensional atmospheric turbulence spectrum (Ostashev and Wilson 2000; Wilson 2000b). These models, based on shear and mixed-layer similarity scaling theories, give much more realistic results than previous formulations.

ABFA's derived calculations (probability of detection, direction-finding accuracy, etc.) are performed by partitioning the overall source spectrum into a finite set of bands. The number and frequency limits of the bands are a part of the source spectrum description. Each band has its own characteristic frequency f_c equal to the spectrally weighted first moment for the band. The three basic ABFA calculations are applied at the characteristic frequency and are assumed to be valid throughout the entire band. For example, the sound pressure level in a given band *n* is calculated from

$$\mathrm{SPL}_n = 10 \log \int_{f_{\ell,n}}^{f_{u,n}} S_n(f)\,df - \mathrm{TL}(f_{c,n}),$$

where $f_{\ell,n}$ and $f_{u,n}$ specify the lower and upper frequency limits for the band, $S_n(f)$ is the spectral level for the band, and $\mathrm{TL}(f_{c,n})$ is the transmission loss at the characteristic frequency. The SNR for a band is defined as

$$\mathrm{SNR}_n = \mathrm{SPL}_n + 10\log \int_{f_{\ell,n}}^{f_{u,n}} N(f)\,df,$$

where $N(f)$ is the noise spectrum.

Probability of detection calculations are based on SNR_n and the signal fluctuation statistics in each band. The overall probability of detection represents the probability that the signal will be detected in *any* of the frequency bands.

The direction-finding accuracy calculation is based on a Fisher information analysis. The inverse of the Fisher information (called the *Cramer-Rao Lower Bound*, or *CRLB*) specifies the minimum variance in the error between the estimated and actual directions of wavefront arrival (Wilson 1998a). The Fisher information corresponding to each band, $J_n(\psi)$, is calculated separately using SNR_n and the coherence evaluated at $f_{c,n}$. Assuming that the signal in each band is statistically independent from the others (a safe assumption in typical scenarios), the overall Fisher information available for source direction finding is found simply by summing; that is, $J(\psi) = \sum_n J_n(\psi)$. The direction-finding calculation displays $J^{-1/2}(\psi)$ in degrees.

Location- and velocity-finding accuracy are determined by combining the direction-finding accuracy from multiple arrays. This process is based on a minimum variance (stochastic inverse) formulation discussed in the earlier technical report (Wilson 1998b).

4. AWAUI AND RAD

ABFA incorporates two complementary tools, the Acoustic Waveform Analysis User Interface (AWAUI) and the Receiver Array Designer (RAD). The respective purposes of these tools are to develop new source and new receiver descriptions for ABFA calculations. After new descriptions are created, they automatically appear on the Source and Receiver pull-down menus.

AWAUI, shown in Figure 3, is a versatile tool for analyzing digitized sound recording. It is invoked by ABFA's "wizards" for creating new source and noise background descriptions. Several input file formats are supported, including .au, .wav, and the extensive library of binary data files in the ARL's database. (See Section 6.) AWAUI calculates the power spectrum from the input recording. An ABFA banded spectral representation (see next section) is generated, either through automated algorithms or by manually configuring bands with the mouse. The spectral levels are calibrated according to the measurement conditions, mainly the position of the microphone relative to the source and the ground surface type.

The upper graph in the AWAUI display shows the complete digitized recording as loaded from the input file. The middle graph is a close-up of the segment of the clip currently being analyzed. To analyze a different section, drag the mouse while pressing the left button, thereby outlining a box around the desired part of the signature in either the upper or middle graph. The middle graph will be updated when the mouse button is released. Pressing the right mouse button plays the sound segment over the computer's speakers. The lower graph shows the power spectrum of the segment, along with the overlaid ABFA banded representation. Signal-processing parameters and measurement conditions can be changed at any time from the "Options" pull-down menu at the top of the AWAUI window.

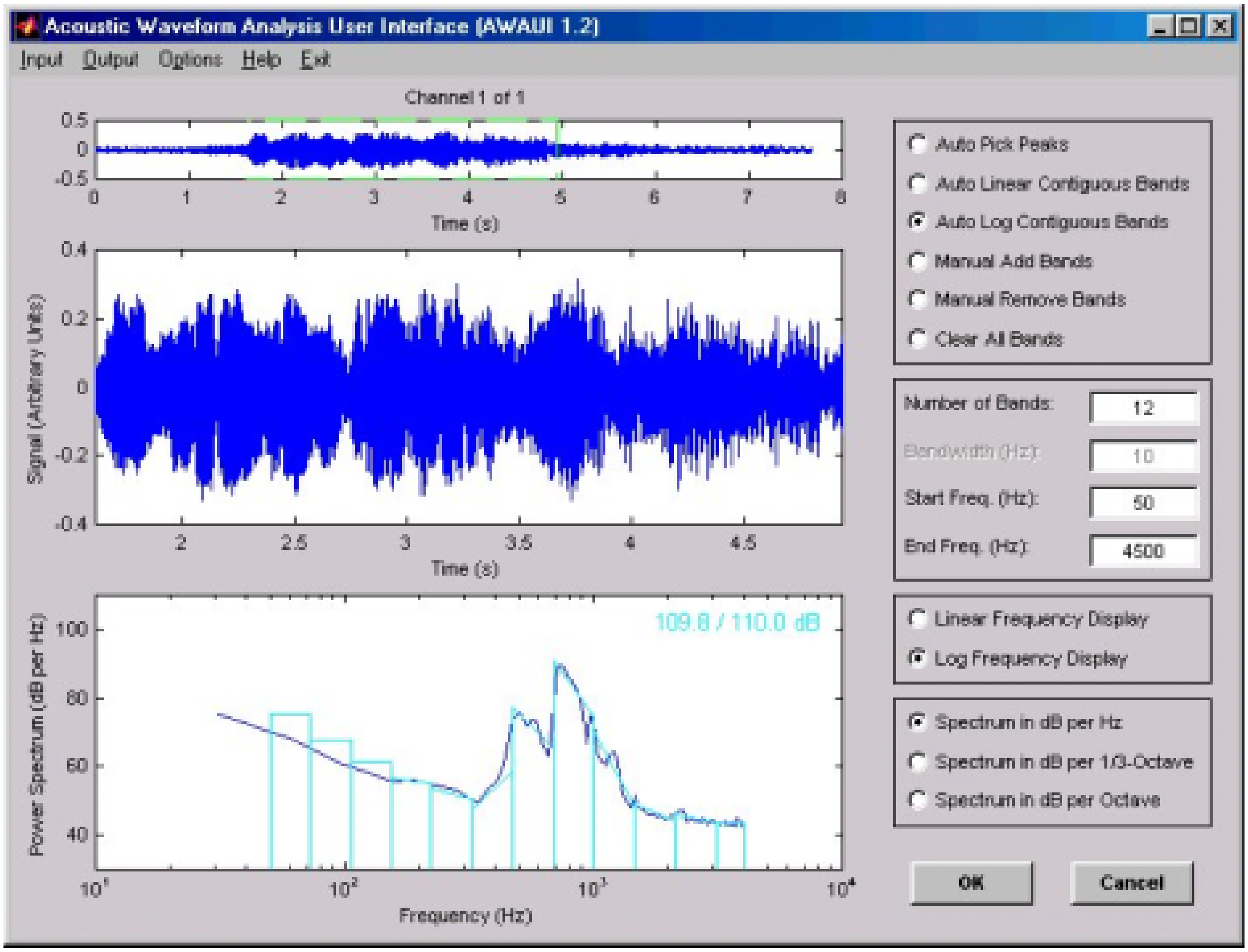

Figure 3. Acoustic Waveform Analysis User Interface (AWAUI) display.

ABFA also invokes AWAUI to allow users to view and edit the spectra of sources and noise backgrounds. An abbreviated display is generated, with only the spectral plot (the lower graph in Figure 3) visible.

RAD (Figure 4) is an interactive tool for displaying and laying out the positions of individual sensors in an array. It is part of the Create New Receiver wizard, and is also called by ABFA to display the positions of existing arrays.

The left side of the RAD window shows the sensor layout. The scale of the sensor layout display can be adjusted with the slider bar underneath. New sensors can be added to an array configuration simply by clicking on the desired position with the mouse. Existing sensors are deleted by clicking on them.

The right side of the RAD window shows the directional gain possible for the array. By adjusting the phase angles of the array signals before combining them, an array can adaptively steer its main response beam, hence improving SNR. The possible gain depends on the frequency as well as the sensor layout. RAD's directional gain plot is the theoretical maximum obtainable. The frequency of the calculation can be adjusted with the slider bar underneath.

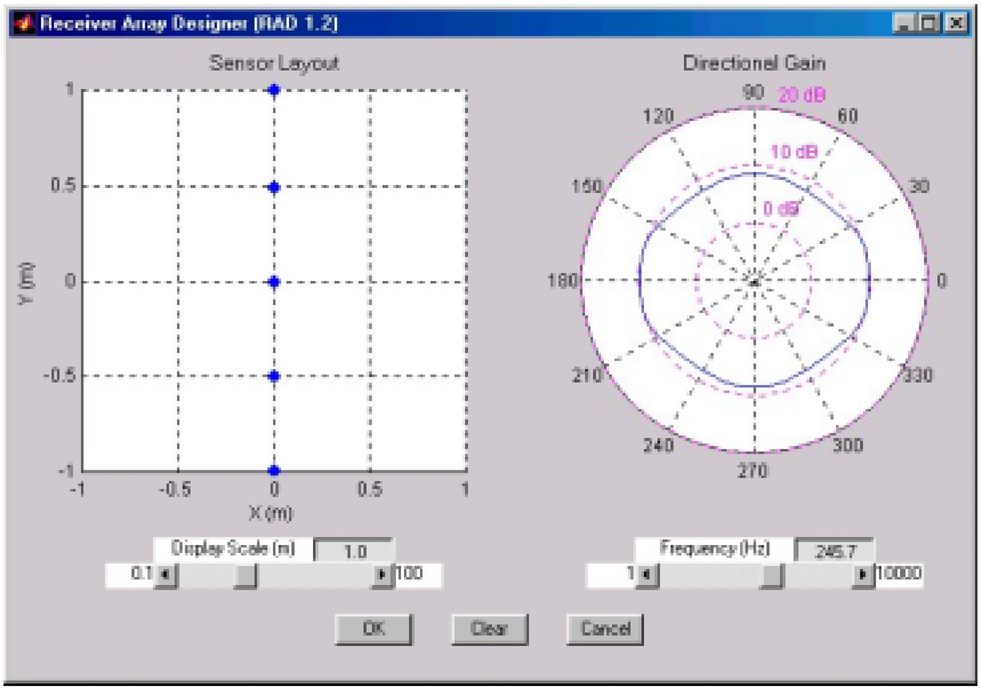

Figure 4. Receiver Array Designer (RAD) display.

5. ATMOSPHERIC MODELS AND NETWORK INTERFACE

As part of the DoD Smart SensorWeb, new capabilities for network retrieval of atmospheric data have been built into ABFA. These capabilities make use MATLAB 5.3's experimental Java interface.

The "Load Surface Weather Message" option on the Weather menu provides retrieval of surface observations from a pair of FTP sites: the National Weather Service's METAR (Aviation Routine Meteorological Report) site (ftp://weather.noaa.gov/data/observations/metar), updated hourly for surface stations around the world, and the MIT/Lincoln Laboratory WeatherWeb site, updated each half hour for several stations in western Massachusetts. To access the weather message, the user simply enters the four-character international station identifier code (e.g., KBWI for Baltimore-Washington International Airport). WeatherWeb stations are preceded by a pound sign. If the user does not know an appropriate station identifier code, ABFA can perform a search for nearby weather stations. The user then selects the desired station from a list.

After ABFA retrieves a surface weather message by FTP, it automatically parses the text to determine the information needed by the surface-energy balance model. The near-surface vertical profiles are then estimated just as if the user had entered data manually with the "Enter Surface Data" option. The process is approximate, since the weather messages provide only partial or incomplete information for some parameters. For example, the code "SCT" (scattered) in a METAR message indicates clouds covering 3/8 to 4/8 of the sky; since ABFA needs an exact value, it interprets SCT as 40%. Fortunately the end effect that interpretations such as this have on the vertical wind and temperature profiles is small.

The surface-weather message retrieval capability is complemented by ABFA's "Automatic Timed Execution" feature. When this feature is invoked, ABFA automatically retrieves surface-weather messages at a user-specified time interval (say, every one or two hours). The newly retrieved weather data are then used to recalculate the currently displayed quantity. Hence the sensor coverage display is automatically updated on a regular cycle.

An alternative method for loading surface-weather messages is provided when one or more surface-weather stations are situated in the current ABFA domain. The locations of these stations are plotted as triangles. By right clicking on the triangle marker, several commands can be displayed including "Display Weather Data" and "Load Weather Data." The former simply retrieves and displays the data from the station. The latter retrieves the data and then uses it to update the currently displayed calculation.

The "Load Vertical Profiles" option on the Weather menu allows users to load vertical profiles directly from file. Several formats are supported. These data might come, for example, from weather balloons (radiosondes). Another purpose of the "Load Vertical Profiles" option is to serve as a gateway for retrieving data from numerical weather-prediction models. This capability is activated when ABFA is running on a network with an Army IMETS (Integrated Meteorological System) station. The IMETS station automatically receives forecasts from the Navy's Operational Global Atmospheric Prediction System (NOGAPS) via a satellite transmission. The forecast data are stored in the IMETS Gridded Meteorological Database (GMDB) and subsequently used to initialize runs of the Army's Battlescale Forecast Model (BFM). When a BFM run is completed, these forecast data are also stored in the GMDB. In the future, the Penn State/NCAR MM5 mesoscale forecast model will be added to the GMDB.

ABFA accesses all currently available forecast data (BFM and NOGAPS) from the GMDB. This is accomplished through the MATLAB Database Toolbox and Java Database Connectivity (JDBC). (The GMDB is an ODBC-compliant Informix database.) Although the underlying process by which the forecast data are obtained and translated is quite complex, the user is guided through a simple process involving selection of only the forecast run and time. ABFA selects the vertical profile from the forecast grid point nearest to the ABFA domain origin. Surface-layer turbulence parameters are estimated from the lowermost two forecast levels.

6. INTERFACE WITH THE ARL DATABASE/ATR LAB

The ARL Acoustic Signal Processing Branch has developed an extensive collection of acoustic target signatures and automatic target recognition (ATR) algorithms. These signatures and algorithms are integrated into a unique, versatile user interface (Nguyen et al 1997), called the ARL Database/ATR Lab. We have developed and continue to work on interfaces for ABFA to draw on the Database/ATR Lab and vice versa.

Our first effort involved building into AWAUI a routine for reading recordings with the format of the target signature database. This was accomplished in Summer 1999. More recently we have developed an interface that makes ABFA and AWAUI "self-configuring" when launched from within the ATR Lab. When the user selects a target signature from the database and clicks on the ATR Lab's AWAUI button, AWAUI automatically loads available Global Positioning System (GPS) data for the sensors and target, calibration data for the sensors, and the ground type. The signal is then calibrated and adjusted for the measurement conditions (using the impedance plane model discussed in Section 3), thereby producing a standard plot of the target power spectrum at a free-space distance of 1 m.

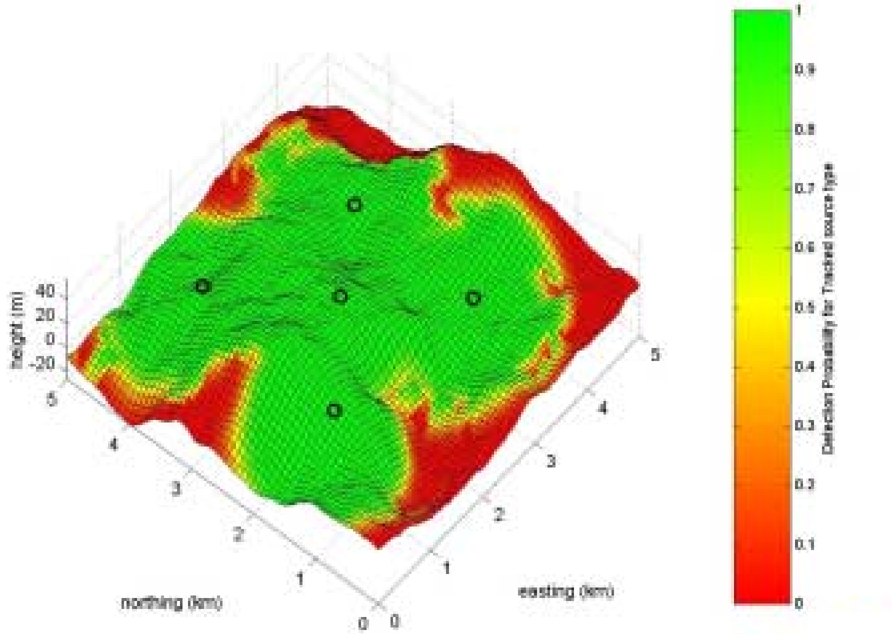

Figure 5. Example calculation for probability of detection in early morning desert conditions.

In a similar vein, when the ABFA button in the ATR Lab is pressed, a “gateway” routine is first called to create a new set of ABFA parameter files. These files incorporate information on the time of the recording, the target and sensor positions, the ground surface, the weather conditions, and (if a DTED CD-ROM is available) the terrain elevation. When ABFA is subsequently started, these files are loaded to configure a simulation. This capability will be valuable in verifying ABFA’s sensor performance predictions. It also allows users to easily play “what if” scenarios, such as calculating detection ranges for ground types and weather conditions different from those of the actual experiment.

We have also begun work on two additional links between ABFA and the ATR Lab. The first is to use the propagation routines in ABFA to “recalibrate” target signatures in the database for alternative atmospheric environments. The basic idea is to calibrate the transfer function between the target and the receiver in the environment in which the signal was initially recorded, and then remove it to determine the initial spectrum at the target. The user would then set the ABFA’s environmental variables to values characteristic of a new environment of interest, and ABFA would subsequently adjust the power spectrum using the transfer function in this new environment. In this manner, virtual databases could be compiled for environments without actually performing experiments in them. This capability might alleviate (but not eliminate) the need for expensive field testing in a variety of environmental conditions.

The second new link would be to use ABFA as a computational engine for generating synthetic time signatures that can be loaded by the ATR Lab algorithms. The ATR algorithms would pass the results back to ABFA to compile and display the results. In this manner ABFA would serve as a powerful interface for testing ATR algorithms in realistic atmospheric environments.

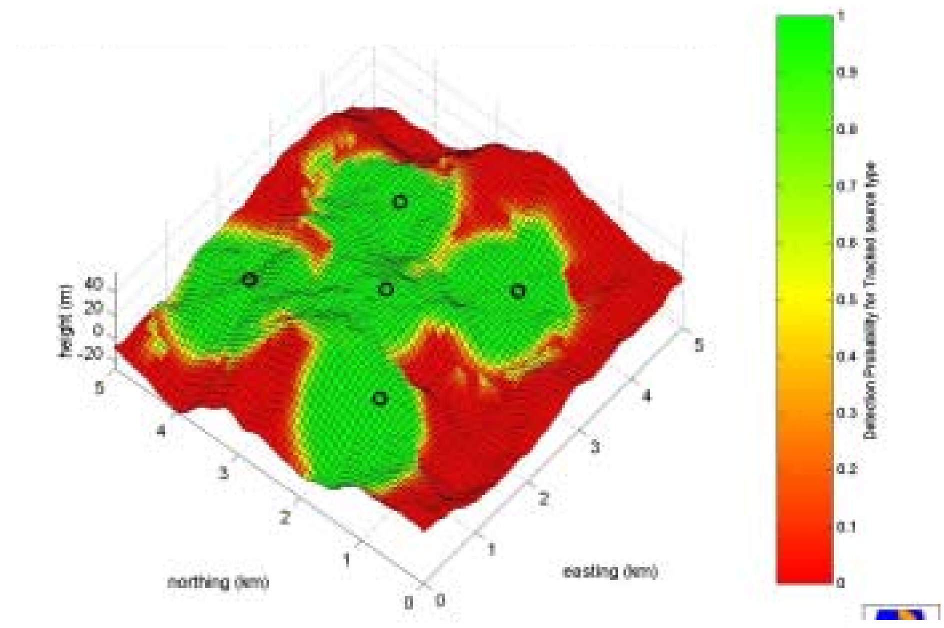

Figure 6. Example calculation for probability of detection in mid-afternoon desert conditions.

7. EXAMPLE CALCULATIONS

This section presents example calculations of the performance of acoustic sensors operating in desert conditions. The calculations are based on actual surface-weather observations collected at the El Paso, TX, airport. The surface-energy balance model described earlier is used to estimate the mean vertical refractive profiles and turbulence parameters from the surface data. The ground properties are characteristic of sandy soil. A simple three-banded spectrum, representative of a heavy tracked vehicle, is used for the source. The receivers consist of six-microphone arrays, with microphones equally spaced around a 1-m radius circle. The noise background is characteristic of quiet, rural conditions. A synthesized terrain based on a fractal model, with an outer length scale of 3 km and standard deviation for the height equal to 25 m, is incorporated into the calculations.

Calculated probability of detection for a network of five receiver arrays is shown in Figures 5 and 6. Figure 5 is based on data collected at 0600 on 21 September 1998. The preceding night had been a clear one, as is typical for this desert region, with weak southerly winds at 2.6 m/s and a temperature of 25 °C. Figure 6 is based on data collected at 1300 on the same day, at which time the wind speed had increased to 5.1 m/s from the northwest, and the temperature had increased to 31 °C. The coverage of the network clearly diminishes during the afternoon hours. The main causes are upward refraction resulting from the lapse temperature profile, and increased wind noise.

Target location-finding accuracy for the same two atmospheric conditions is shown in Figures 7 and 8. The number of receiver arrays has been increased to nine, because roughly twice as many nodes are required to perform location finding than detection, so that at least two receiver arrays can "triangulate" the source location. The linear regions of poor accuracy that connect pairs of receiver arrays occur because the bearings from the two arrays cannot be combined to give an accurate location in these regions.

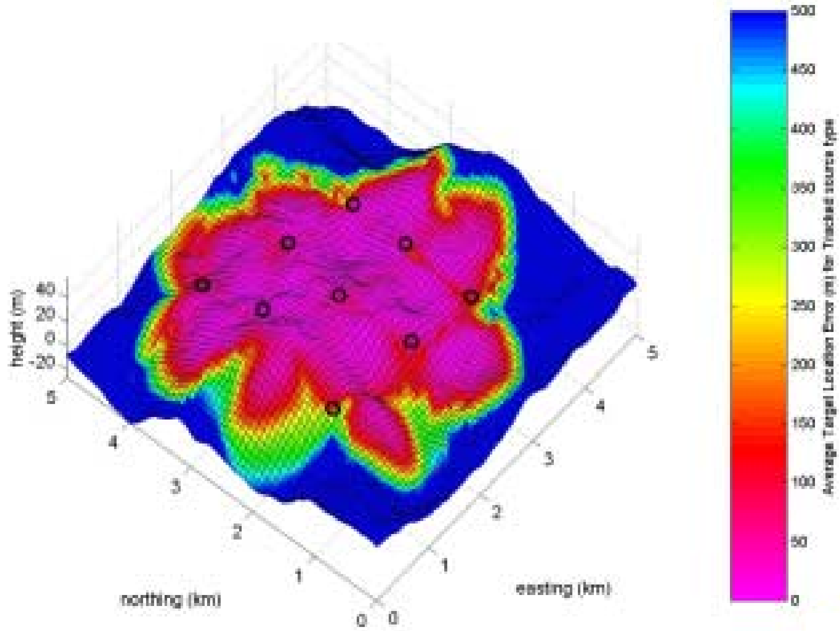

Figure 7. Example calculation for target location-finding accuracy in early morning desert conditions.

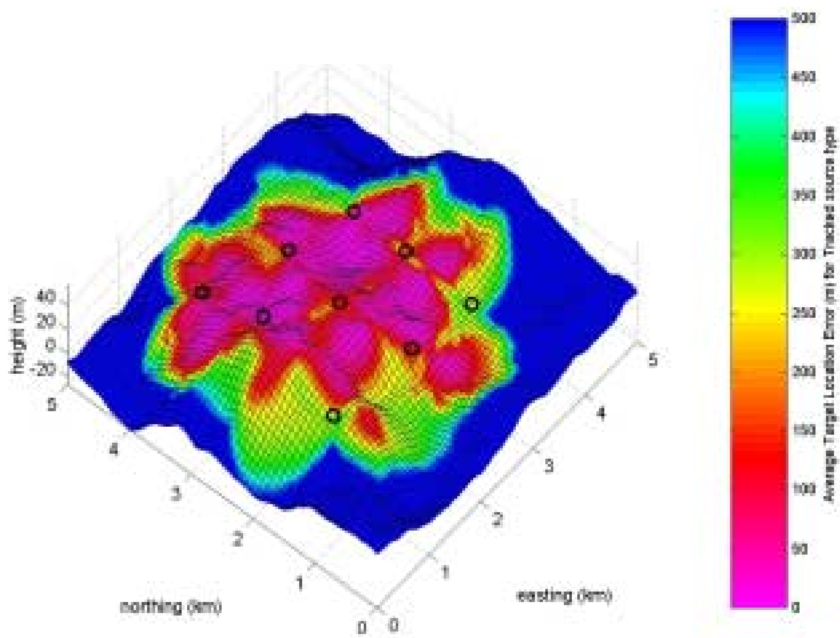

Figure 8. Example calculation for target location-finding accuracy in mid-afternoon desert conditions.

8. CONCLUSION AND RECOMMENDATIONS

Atmospheric conditions significantly impact acoustical sensor performance. ABFA models these effects by integrating recent physics-based analyses of sensor arrays operating in atmospheric turbulence, statistical models for signal fluctuations driven by turbulence, advanced numerical methods for predicting acoustic transmission loss, and a surface-energy balance model to reconstruct atmospheric profiles from standard surface-weather observations. Several future enhancements to ABFA are planned:

1. Allow specific detection, identification, bearing, and localization algorithms to be loaded as plug-in modules. ABFA would provide a powerful simulation environment for testing such algorithms.

2. Improve the Cramer-Rao Lower Bound (CRLB) calculations of bearing and localization errors, including a realistic assessment of knowns/unknowns in the problem and coherent processing between arrays. (The current CRLB implementation assumes that the only unknown quantity is the target bearing; the range and environmental parameters are assumed to be known. The significance of these assumptions is not well understood at present.)

3. Perform coupled acoustic/seismic calculations, by extending the fast-field program to include seismic wave propagation.

4. Extend the turbulence model to include wind gustiness. Our analysis of experimental data shows wind gustiness to be quite important, particularly in conditions of low mean wind.

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