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REDUCING THE IMPACT OF NOISE ABATEMENT STRATEGIES ON AIRPORT CAPACITY BY FORECASTING NOISE

Robert Sharman and Arthur Shantz
Research Applications Program
National Center for Atmospheric Research
Boulder, CO U.S.A.
sharman@ucar.edu

Abstract

Operational aircraft have noise “footprints” that are determined not only by the operational configuration of the aircraft but also by the highly variable atmospheric environment through which the sound is propagating. Current approach and departure routes do not reflect these inherent and dynamically changing patterns of noise dispersion and propagation in the atmosphere in attempts to reduce population exposure to aircraft noise. Instead, airport approach/departure routes primarily depend upon more static climatology and population analyses to reduce exposures to audible aircraft noise. This paper attempts to quantify the influence of meteorological variability on the shape and extent of aircraft acoustic footprints by using a state-of-the-art sound propagation model to predict the acoustic propagation patterns. Both idealized meteorological profiles and actual profiles from soundings are examined. A particular case is studied in detail, and compared to the U.S. SAE AIR 1845 noise standard, which has been incorporated into the FAA Integrated Noise Model (INM). For the cases examined, the acoustic footprint is usually smaller than that predicted by the INM, but can also be substantially larger in particular directions around the aircraft due to sound channeling by low level wind shears. With the combined use of a sound model and meteorological measurements and/or forecasts it may be possible to develop runway use strategies to minimize population exposure to aircraft noise while reducing the adverse effects of noise abatement procedures on airport operations.

1. Introduction

Current approach and departure routes at a number of airports reflect attempts to balance flight operations and population densities to achieve noise abatement objectives. However, the patterns of noise propagation and dispersion depend strongly on the variability of the weather. In contrast, most of the current noise abatement constraints on airport departure routes are continuous and virtually constant for all meteorological conditions. They do not vary with the weather, and this may present a potential opportunity to enhance airport capacity.

This study is an attempt to quantify the effect of the meteorological variability on sound propagation from aircraft and consequent sound levels at the surface. Both idealized meteorological profiles and actual profiles from soundings are examined. In either case, the meteorological profile is input to a general use sound propagation model known as the fast field program (FFP). This is a quasi two-dimensional, single frequency model that was originally developed for predicting sound propagation in the ocean. It has been extended to atmospheric applications as well (Lee et. al., 1986, Franke and Swenson, 1989, Noble and Marlin, 1995). With the aircraft modeled as a single frequency source at various flight levels in the atmosphere, the FFP derives the sound propagation pattern in a vertical plane at a particular azimuth from the source, taking into account spherical spreading, molecular absorption, refraction, and surface interactions. By considering a full range of azimuths (as in Figure 1), a two-dimensional plot of sound levels in a horizontal plane surrounding the source and containing the receiver may be constructed. Further, if the spectral content of sound generated by a particular aircraft is known, the model can be run with different frequencies, and the results A weighted to give the sound level at the receiver. However the effect of atmospheric variability can be examined by simply looking at one individual frequency representative of the aircraft. For most of the cases shown here, unless otherwise noted, a frequency of 1000 Hz was used. At the time of writing this report, only aircraft sources at the surface (i.e., on the runway) have been considered. For this, the source is taken at a height of 10 m, and the receiver at a height of 1 m. Higher heights of the source (modeling takeoff patterns for example) will be investigated subsequently.

In an attempt to quantify the source levels in a realistic manner, the intensity of the source is derived from an example given in Appendix E of the SAE standard for airplane noise prediction (SAE AIR 1845, 1986). In that appendix sound levels are derived for a hypothetical two engine jet aircraft on departure. Noise-power-distance (NPD) data is given, and that data, for the hypothetical takeoff configuration at brake release, is used to normalize the sound levels computed from the FFP. The sound level pattern derived from the SAE Standard algorithms (which are implemented in the FAA INM) for this example is shown in Figure 2. In this and all subsequent figures, sound patterns are shown as colored contour plots of sound levels in dB, at the receiver height of 1 m, over a two kilometer area with the source at the center of the figure. A color bar along the upper right of the figure can be used to quantify the levels in the pattern. In the figure, the standard adjustments for duration and directivity have not been included, since these effects are not modeled in the FFP. Note the completely symmetric (in azimuth) structure of the pattern, and that the 80 dB level is at a radial distance of about 1 km.

In the next two sections this pattern will be compared and contrasted with patterns derived from the FFP using first, idealized meteorological profiles, and second, actual meteorological profiles gathered from one year’s worth (1998) of sounding data from Upton NY, USA. Upton is a designated World Meteorological Organization (WMO) sounding station, and was chosen for its relatively close proximity to JFK International Airport (about 80 km east). Soundings are taken there routinely twice daily, at 0 UTC and 12 UTC, so this represents over 700 sample atmospheric structures.

2. Results with ideal atmospheric structures

To better interpret results using the FFP with the actual sounding data from Upton, it is instructive to first consider some idealized atmospheric profiles. The obvious first case to examine is the vertical structure corresponding to a “standard atmosphere.” The standard atmosphere actually has a precise definition in terms of pressure, temperature, and density profiles (e.g., U.S. Standard Atmosphere, 1966). However winds and humidity are not specified. Here the dry, standard atmosphere is used with the SAE standard prescribed headwind of 4 m/s and dry air for noise calculations. Figure 3 shows the FFP sound pattern produced for a dry, standard atmosphere with an east wind of 4 m/s, and for three different source frequencies, 100, 1000, 10000 Hz. The patterns are azimuthally symmetric, and because the effect of molecular absorption is frequency dependent, the radius of the pattern increases as the frequency decreases.

In an attempt to compare the pattern to the pattern computed from the SAE standard in Figure 2, this case was also integrated over frequency and A weighted. Although a precise comparison is not possible since the spectral distribution of noise from the hypothetical two engine aircraft was not given in the standard, using two engine spectral class data from the INM (see FAA DTS-34-FA065-LR1, 1999) should give a reasonable comparison. The data for INM spectral departure class 102 was used together with A weighting of the frequency dependent response output from the FFP to derive the pattern shown in Figure 4. Because the lower frequencies are weighted the least in the A weighting response, that pattern is relatively small in size, and is somewhat smaller in size than the 1000 Hz pattern shown in Figure 3b. Note that the pattern is only about one-half the size of that shown in Figure 2, implying the INM standard overestimates the sound levels. But this needs to be based on a more rigorous comparison before specific and general conclusions should be made.

These patterns are all symmetric, or nearly so, since the effect of temperature gradients acts the same in all propagation directions, and the wind speed is generally much smaller than the speed of sound. But if wind shear is now introduced, an azimuthal dependence will appear for a favorable alignment of wind direction and shear magnitude. This is demonstrated in the pattern shown in Figure 5 for a east wind increasing with height, but otherwise the conditions are the same as those used to construct Figure 3b (i.e., 1000 Hz source and a standard atmosphere). Figure 5a is the result obtained for a small shear of .01 m/sec/m and shows the pattern is expanded slightly to the left (west). Figure 5b shows the result obtained with a larger value of shear of .25 m/sec/m. Here the symmetry is almost entirely destroyed, with propagation dominantly to the west and taking on a bell-shaped pattern in the left half of the plane. Reflection from the surface and refraction aloft causes a reinforcement of the intensity near the left boundary of the figure. The pattern in the right half of the plane (to the east of the source) is still fairly uniform, but the influence is somewhat smaller than in the no shear case. These bell-shaped patterns are obtained in the more general cases with shear vectors rotating with increasing height, as will be demonstrated in the next section.

3. Results with actual atmospheric structures

As mentioned in the introduction, in order to gain an appreciation of the extent of day-to-day variability in sound levels due to varying meteorological conditions, the actual twice daily sounding data for Upton NY was used as input to the FFP. For the sample sounding the east and west components of the wind were decomposed into components parallel and normal to each radial plane computed by the FFP. In each plane, wind shear within the plane is computed only from the component tangent to the plane. A sample of resulting patterns for a 1000 Hz source are shown in Figure 6. Because substantial wind shears are usually present in the lower atmosphere, the sound propagation patterns rarely look like that derived from the standard atmosphere with constant wind, and instead show the bell-shaped pattern indicative of favorable horizontal propagation in certain azimuthal directions. These patterns occur regardless of the season and time of day. If these patterns were averaged over all samples from the year, it is probable that the pattern would be roughly symmetric, and be about the same size as the INM example in Figure 2.

4. Summary and conclusions

This preliminary look at the effect of atmospheric variability on aircraft sound propagation has shown that:
(1) the sound propagation footprint emanating from an aircraft undergoes substantial day to day variability, both in the size of the footprint, and in the azimuthal variations;
(2) the azimuthal variations are due mainly to low level wind shear;
(3) the size of the acoustic footprint as determined by a state-of-the-art sound propagation model is smaller than the INM specified footprint.

However, the generality of these results needs to be substantiated with more systematic case studies. In particular, for airport operations, the last result needs further support. At a minimum the cases studied and presented here need to be extended to include elevated sources, and all cases should be computed with A weighting of the results from the individual frequencies. These tasks have already been undertaken and will be presented at the seminar. However, in the likely event that the results presented here are more generally applicable, this suggests strategies that may be invoked in future airport planning and operations that may increase airport capacity by taking advantage of days/times when the sound propagation is minimal. For example, if an aircraft is departing from an east coast terminal which is close to the coast, during times when the environmental conditions throw the sound pattern over the water, a takeoff heading could be chosen that would minimize exposure to population areas over the land. Other scenarios could be envisioned. But to take advantage of these, it would be necessary to be able to predict the sound levels by using a sound propagation model such as the one used here. This, in turn, would require knowledge of the vertical structure of the atmosphere, especially the vertical shears of the horizontal winds. This may be obtained from real time measurements at the airport, e.g., by rawinsondes or wind profilers, or from forecasts obtained from local numerical weather prediction (NWP) models. At this point in time however, most NWP models are too coarse in both their vertical and horizontal resolutions to be able to portray the vertical structure of the atmosphere with sufficient accuracy to be useful as input to a sound propagation model. However, these models are constantly evolving with higher resolutions, and within the next five years the resolution may be adequate for sound prediction.

In some regions, NWP models with sufficient resolution are already being run operationally. One example is the The Pennsylvania State University – National Center for Atmospheric

Research Mesoscale Model Version 5 (Penn State-NCAR MM5) used operationally at some of the U.S. Army test ranges. Last year NCAR used a variety of Army test data from a planned explosion at the Aberdeen Proving Ground (APG), MD in February, 1999 to compare and verify noise model output against measured noise at over 20 monitoring locations around the Chesapeake Bay. Sound model predictions were compared to measured noise levels at various locations around the bay following the explosion. In addition, the noise model's prediction of the sound pattern when the model was initialized with a near real-time sounding taken at APG, was compared with its prediction when initialized with "pseudo-sounding" output from a 16 hour MM5 forecast. Results of these experiments showed that MM5's pseudo-sounding for the approximate time and location of the actual sounding resulted in a noise model forecast qualitatively very similar to that used with the near real-time sounding (see Figure 7).

If this meteorological predictive capability were expanded to airports, noise levels could be forecast to select the most efficient approach and/or departure routes by linking noise and weather models to simulate the operational impact of alternative routing strategies at airports, and to minimize population exposure to aircraft noise. In this way it may be possible to attain significant reductions in the number of flight operations constrained by noise abatement procedures, without increasing the population exposure to aircraft noise.

5. References

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Biographies

Robert Sharman is a Project Scientist in the Research Applications Program at NCAR in Boulder, Colorado. Dr. Sharman is currently working on methods to improve turbulence forecasts for a real time analysis and prediction system for use in aviation. He is also involved in noise modeling for the Aberdeen Proving Ground as part of the U.S. Army's 4DWX program. Before joining NCAR, Dr. Sharman was a Senior Engineer at Logicon, Inc., where he was involved in the mission planning of low-observable aircraft. Dr. Sharman received his PhD from UCLA, with a specialty in wave propagation in geophysical flows.

Arthur Shantz is the Deputy Manager for Programs in the Research Applications Program at the National Center for Atmospheric Research in Boulder, Colorado. He is the project manager for the US Army 4DWX program at NCAR. The program will provide very high-resolution, weather forecasts and simulations in an integrated data base management and display system for meteorological analyses and forecasting in tests at national test ranges in the United States. Before joining NCAR, Dr. Shantz was a Senior Evaluator at the US General Accounting Office, an investigative arm of the US Congress, where he was primarily responsible for informing the Congress on the projects comprising the FAA's airspace modernization program. He was a former Senior Systems Engineer at Bendix Aerospace Corporation, a Fulbright Scholar, and has a PhD from the University of Michigan

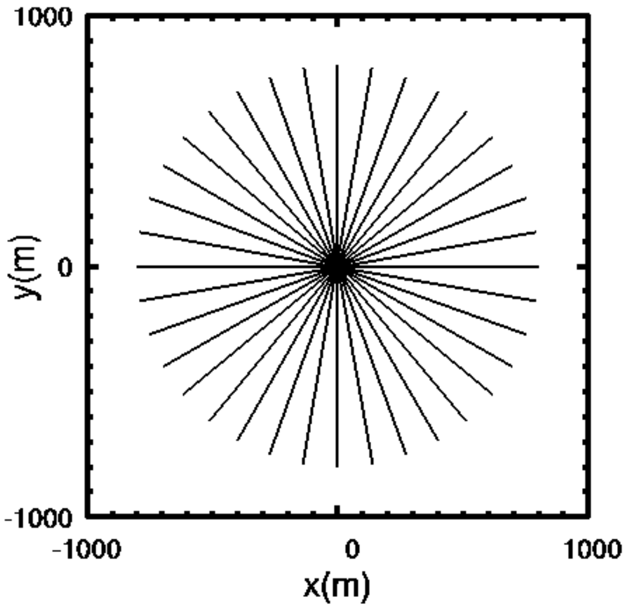

Figure 1. Azimuthal placement of radials used in the FFP computations. Azimuthal increment is 10 degrees. The source is assumed to be at the center (x=y=0). Sound levels are computed along each radial separately and the resulting pattern is contoured in this x-y plane.

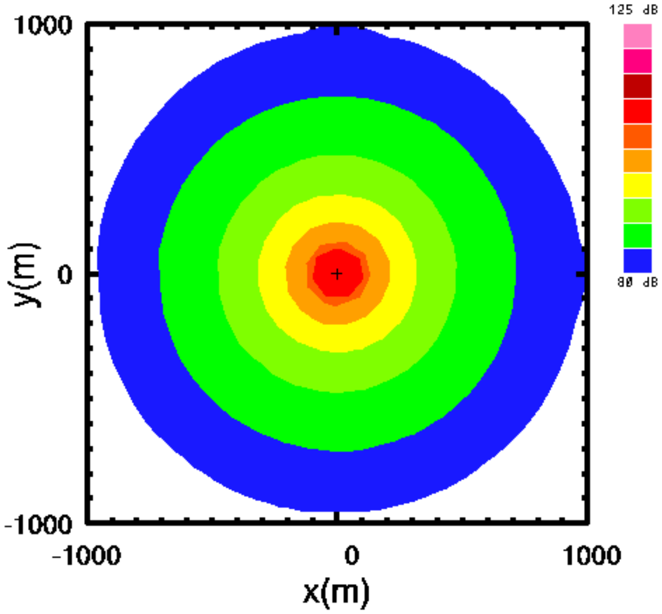

Figure 2. Sound level pattern as computed from SAE AIR 1845 algorithms for the hypothetical two engine aircraft at ground level. The parameters used is this computation were taken from the NDP curves in Appendix E of the Standard. Directivity and duration effects were not included.

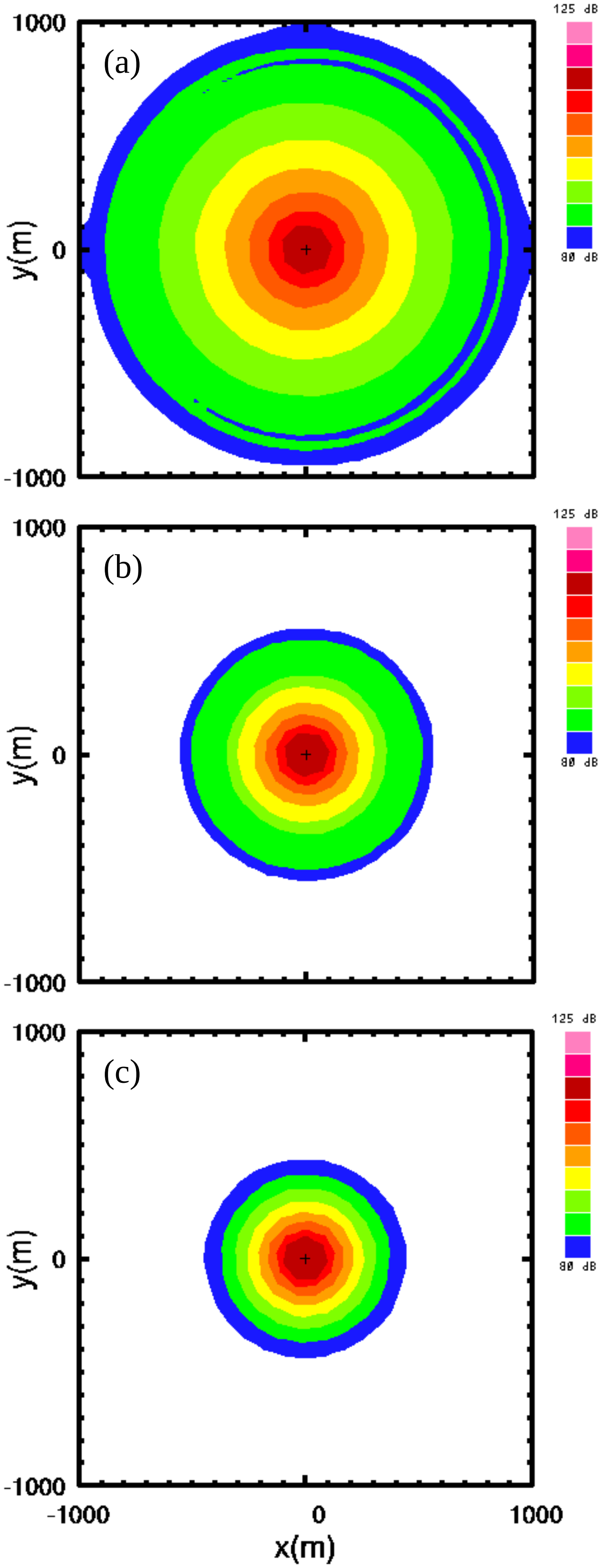

Figure 3. FFP derived patterns for a standard dry atmosphere and a 5 m/s east wind for a source frequency of (a) 100 Hz, (b) 1000 Hz, and (c) 10,000 Hz.

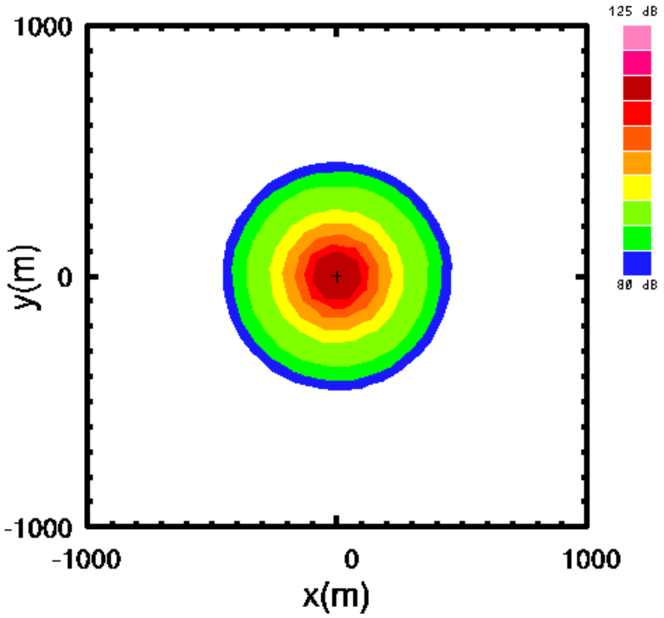

Figure 4. FFP derived sound levels using A weighting and a spectral distribution of source frequency amplitudes specified by INM spectral class 102.

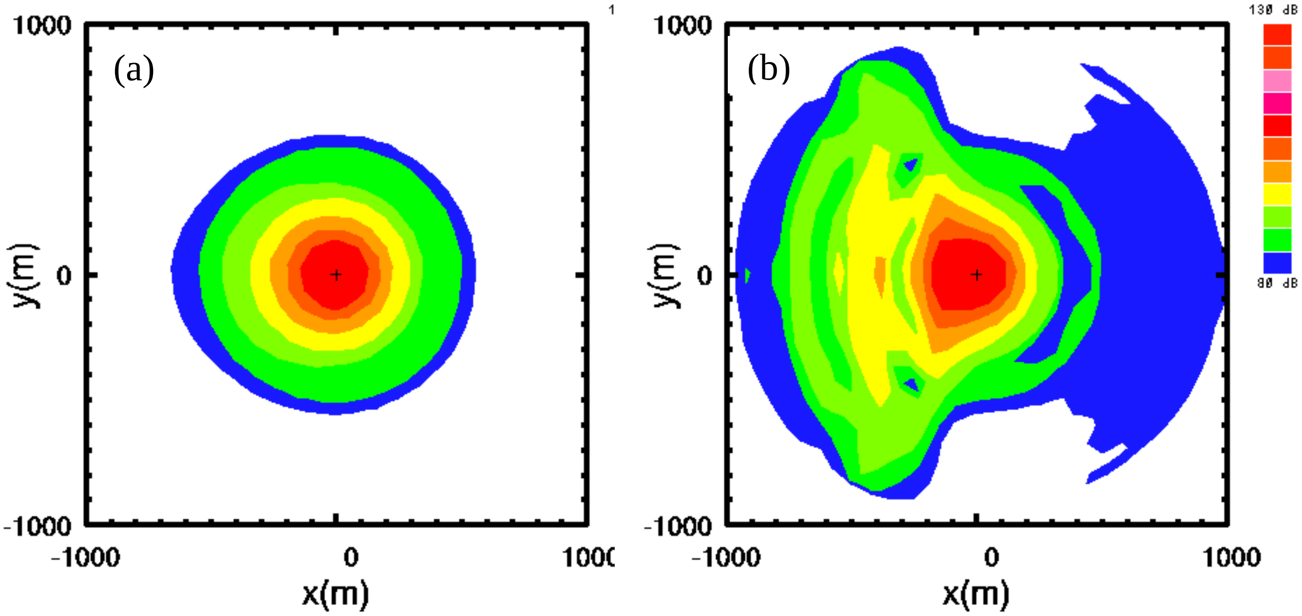

Figure 5. FFP derived sound propagation patterns computed for a 1000 Hz in a standard atmosphere and with a wind shear of (a) .01 /sec, and (b) .25 /sec.

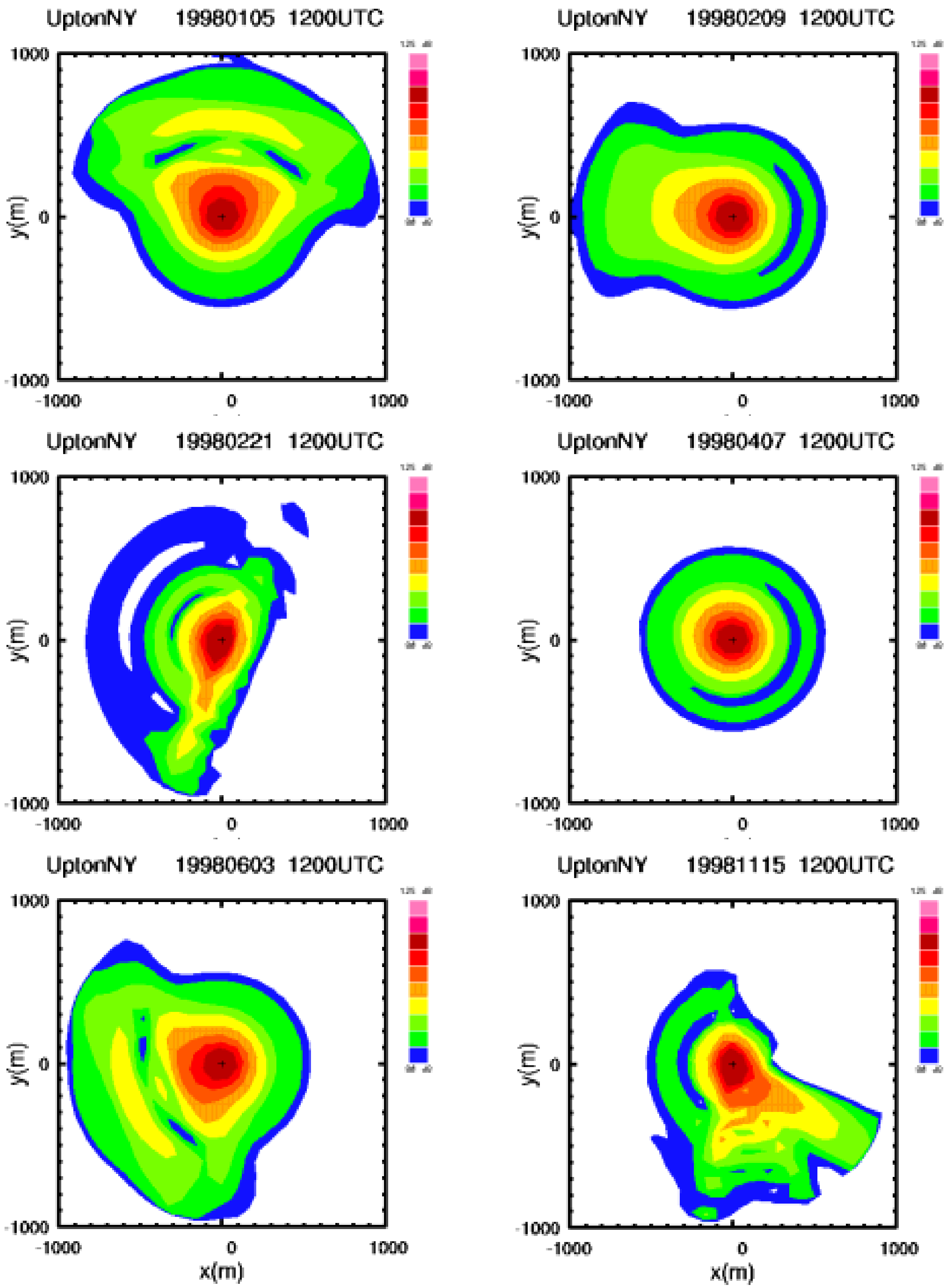

Figure 6. Six different FFP computed sound patterns for a source of frequency 1000 Hz and using six different input soundings from Upton NY for the dates/times indicated.

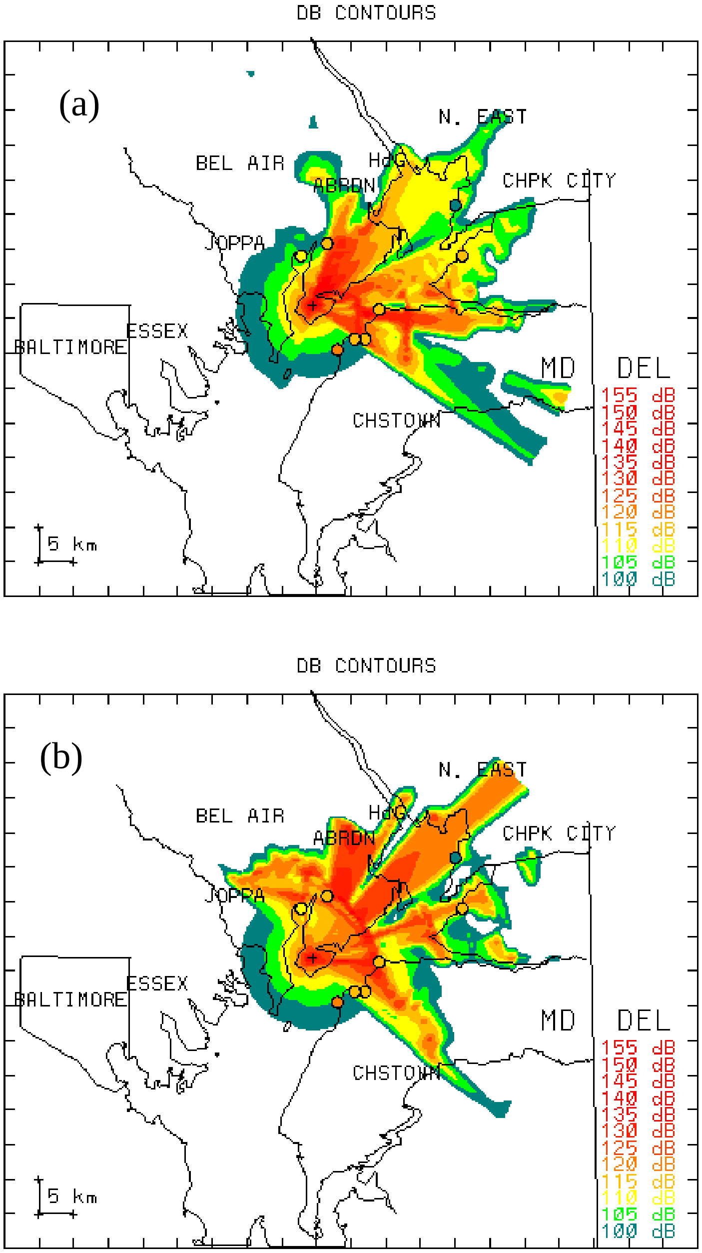

Figure 7. Sound levels (contoured in dB) generated from a blast at the Aberdeen Proving Ground, MD, USA. (a) Pattern produced by the noise model with input sounding data taken near the time of the blast. (b) Pattern produced by the noise model with input pseudo-sounding derived from a 16 hour forecast using the MM5 forecast model.