# **MONET**: **M**et. **O**ffice **N**oise **E**valuation **T**ool

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**ABSTRACT**

A new acoustic model has been developed for the U.K. Met. Office for the prediction of impulsive blast noise from Ministry of Defence (MoD) firing ranges. Noise prediction forms part of the Met. Office's scientific support to the British Forces. The acoustic kernel has been developed by The Department of Applied Mathematics and Theoretical Physics (DAMTP) at Cambridge University. The Met. Office developed the Graphical User Interface (GUI). This paper explains the requirement for such a model and a comparison study between the previous and new models. Verification of the new model was carried out by The Met. Office with the results shown. Planned future work on advanced versions of the model is described.

## 1. Introduction

Prediction of sound from artillery firings and explosives testing is a unique skill asked of meteorologists, stationed at Ministry of Defence (MoD) ranges. With expanding residential areas and more powerful guns, noise nuisance has ignited local concerns, producing numerous claims against the MoD for noise disturbance and in some instances for causing actual structural damage to buildings. Sound modelling allows the forecaster to pinpoint areas of extreme noise and to advise whether to postpone or continue firing.

## 2. Previous model

This requirement was, until recently, met by the Acoustic Prediction Package (APP). This acoustic model uses ray tube theory to forecast areas of enhanced and focused sound. Ray tube theory achieves this by calculating ray trajectories over a series of vertical layers. Predictions are then produced for regions where ray tubes impact the ground. See *Figure 1* for a visually recognisable illustration of how the model works. Rays can be seen to refract downwards and upwards due to differences in the sound speed profile. This method provides a conceptually straightforward approach and meets operational requirements since it is relatively inexpensive computationally.

However it has been recognised that ray tube theory has limitations[1]. Predictions are only produced for regions where ray tubes impact the ground. This results in partial coverage in the area of interest, impeding the forecaster with an incomplete plot. Also *Figure 1* shows that only individual rays can be traced since ray theory breaks down when rays cross. This lack of representation of interference presents a less reliable forecast in focus regions. This weakness leads to a further problem – ray crossing from ground reflection effects. Ray tube models have difficulty representing height and ground texture and their associated sound reflection. Hence a flat surface is assumed and a parametric method is used in an attempt to describe the effect of terrain in dissipating sound energy.

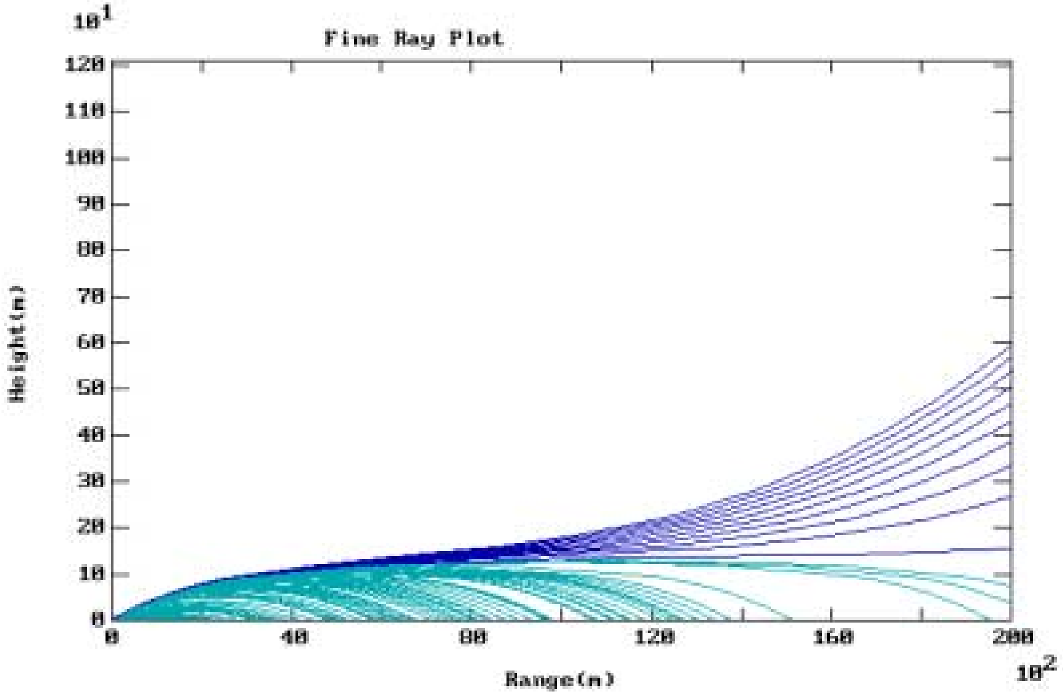


Figure 1: APP ray plot

## 3. New model – scientific benefits

The new acoustic model, MONET, developed by the U.K. Met. Office and Cambridge University addresses such problems. Its acoustic kernel is based on the parabolic form of the wave equation. The parabolic equation describing the propagation of a wavefield through a two-dimensional medium is[2]

$$\frac{\partial E}{\partial z} = -\frac{i}{2k}\frac{\partial^2 E}{\partial x^2} - \frac{ik}{2}(n^2 - 1)E.$$

*E* = *E (x,z)* is the envelope of the propagating field and *k* is the wavenumber of the incident field at the reference refractive index, *n*; *x* and *z* are Cartesian co-ordinates. This paper does not intend to further explain the above equation and the subsequent solution by applying a Fast Fourier Transform (FFT). Further analysis is shown in the references.[2 & 3]

The introduction of a parabolic equation (PE) model allows for interference of sound waves as they travel through the atmosphere and their subsequent interaction with the ground. Here the second benefit of MONET is realised since the model considers terrain height. Hence giving a more physically consistent representation of sound propagation. Compare *Figure 2* with *Figure 1* to illustrate the difference between the two models. The MONET cross-section shows that sound intensity is calculated for the complete x-z plane. Shaded colours show interference fringes where sound waves have merged from ground reflection and attenuation.

MONET handles terrain by ‘removing’ the ground barrier and compensating with an imaginary source. This is a common technique, also used in electrostatics, when the field is confined with a boundary condition. Consider a dipole where the field pattern of a system of two, separated, equal electric or magnetic charges, of opposites signs is modelled by the sum of the fields from the source dipole and its image. The same theory applies to acoustic propagation.

Notice also the first null point where propagation from the source and its image has combined to produce an area of negative interference, paralleling Young’s double slit experiment.

A Gaussian hill (firing point at the origin and hill at 16 km) has also been represented on *Figure 2* to show the effect of terrain on the propagation. The model has been set to a totally reflecting surface and the effect of the hill is quite clear. The hill acts like a barrier and reflects the sound upwards, this in turn upsets the general flow of the field but the pattern is still modelled by the sum of the fields. Notice also the shadow region on the leeward side of the hill.

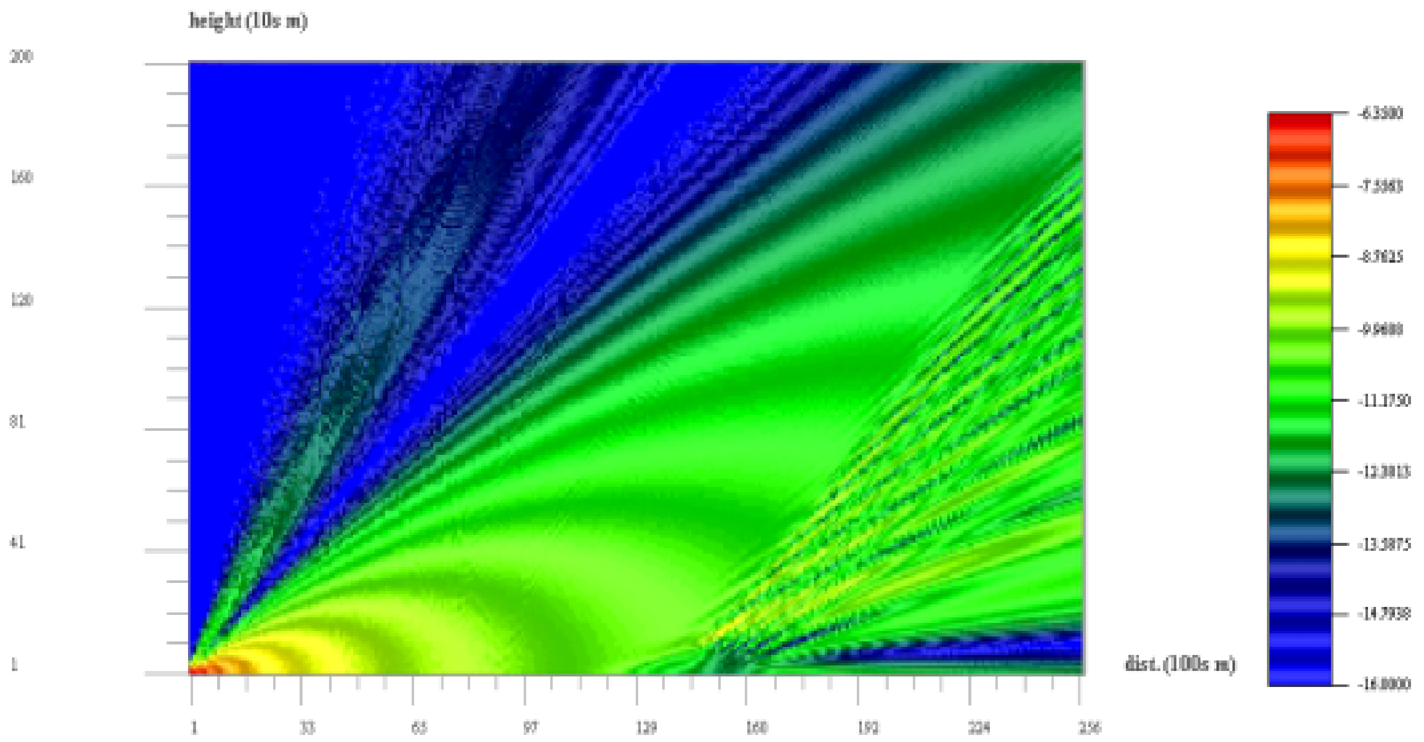


*Figure 2: MONET vertical cross-section of sound intensity (log scale) with Gaussian hill.*

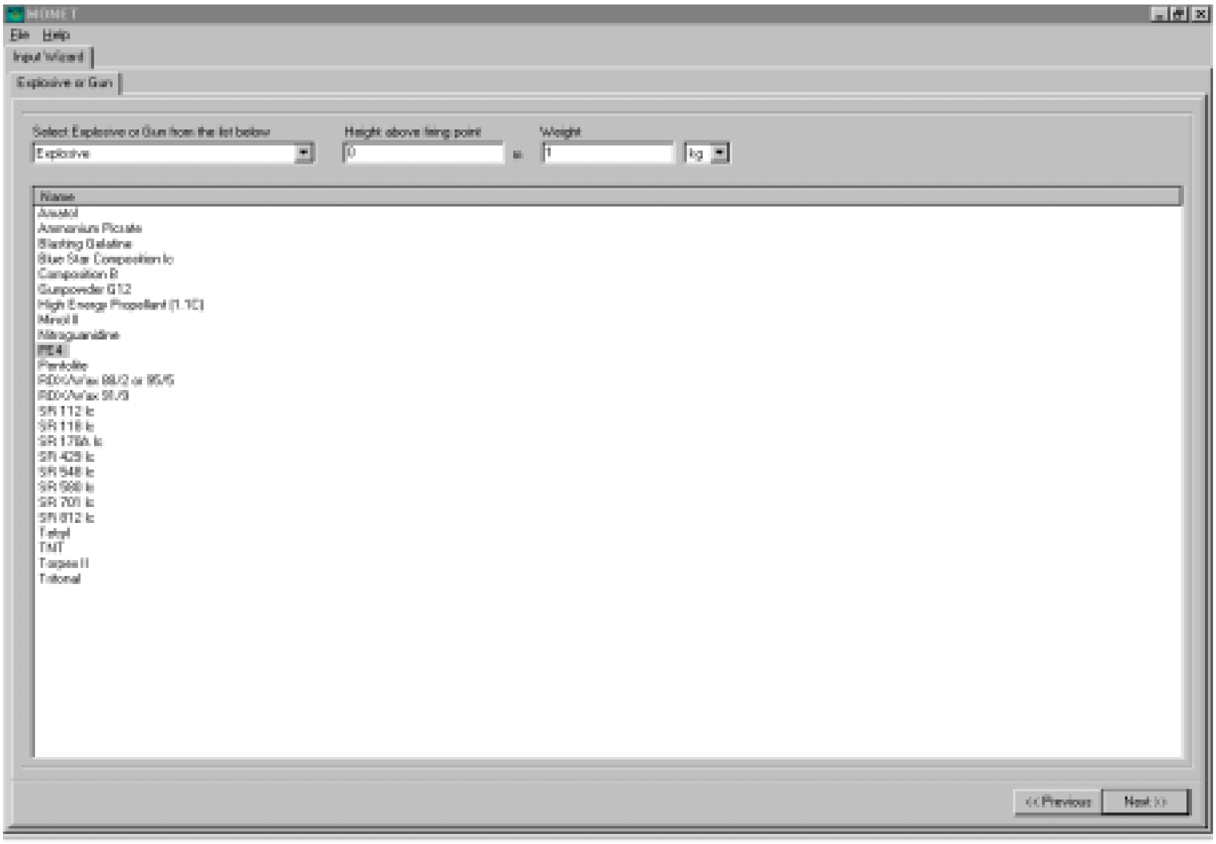


Figure 3: Gun & explosive selection screen

## 4. New model – user benefits

Further benefits are gained from the Graphical User Interface (GUI) as this gives the forecaster a simpler, window-based package. Various model parameters, for example, meteorology and type of explosive, are entered via an input wizard that simplifies the whole input process.

Firstly a specific range and firing point is chosen from the available list. The input wizard then asks for a particular gun or explosive charge weight. The forecaster uses the mouse, to control the particular selection. To give an example, the gun and explosive selection screen is shown in *Figure 3*.

The next parameter entered is the atmospheric input, shown in *Figure 4*. This shows the flexibility of MONET where three sources of meteorological data can be used. Met. Office mesoscale data can be downloaded from the latest Cray supercomputer model run or a local radiosonde ascent can be inserted. A third choice of the ICAO standard atmospheric profile can be used. The forecaster can manipulate all entered data. The data is presented graphically to assist the forecaster identify rogue readings and temperature inversions.

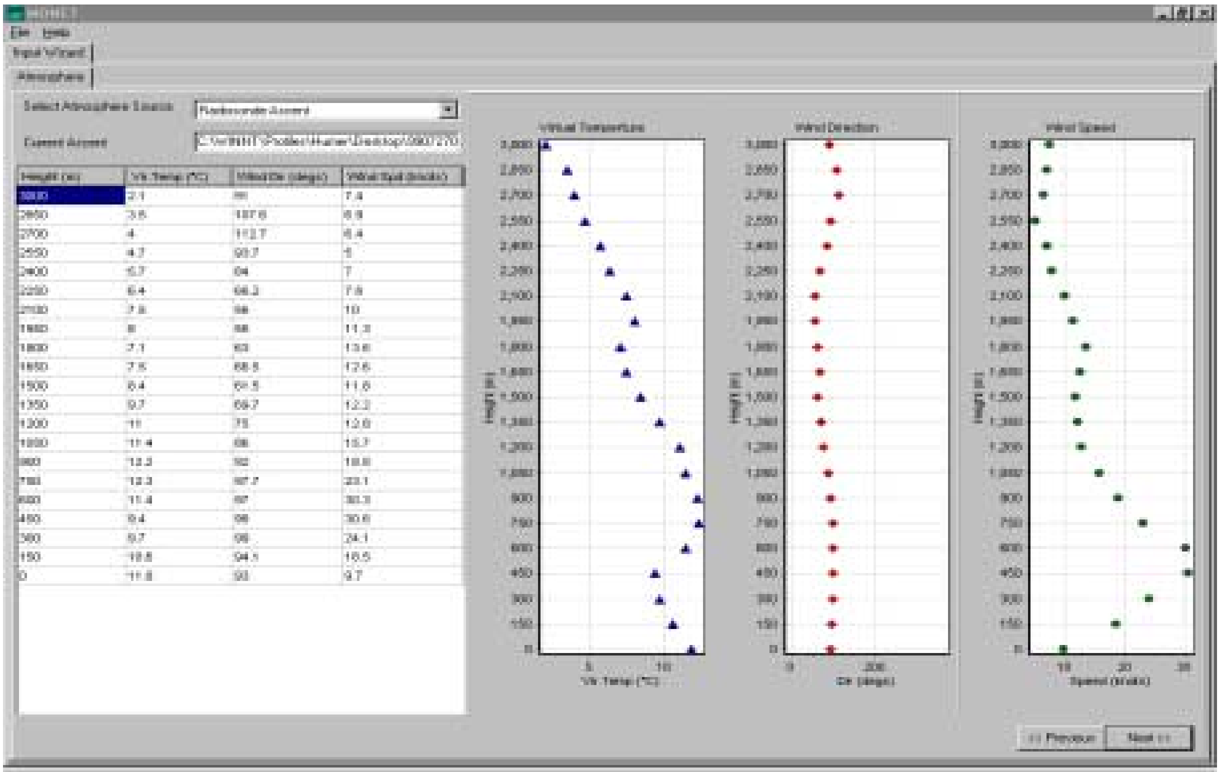

*Figure 4: Meteorological input screen*

The final screen before running the model allows the user to control the output. The model produces peak sound pressure at the surface but the decibel levels that are shown and the accuracy of the plot can be adjusted. These adaptations are made at the options screen wizard, *Figure 5*.

The desired decibel levels are set; 130 dB is specifically chosen, as this is the level that causes most complaints and actual damage to buildings. The area covered by the 130 dB ceiling level must not encroach upon residential areas. Otherwise a lower charge weight or a different firing location must be used or indeed a postponement until favourable conditions avail.

Also shown on the option screen are monitor point selections. This allows the forecaster to pinpoint sound levels at actual grid references that are of specific interest. These locations could mark the perimeter of the range or perhaps towns and outlying villages.

Damage to buildings and windows occurs at the resonance frequency of 40 Hz. The model is set to this frequency although this can be altered. Further choices are available on the advanced options tab. These options relate to the accuracy of the model run. The model works by considering a 360$^o$ circle centred on the firing point, ranging out to 30 km. This is then divided into sectors depending on the number of radials chosen. For example, a choice of 36 radials gives 36 x 10$^o$ sectors. The pressure levels are then extrapolated from the x-z plane (two-dimensional, as in *Figure 2*) to give a three-dimensional 'pie'. The most accurate plot, but slowest run time is achieved with 144 radials at 2.5$^{o}$. Operationally, 36 radials are used. Other attributes relating to smoothing of output and CPU run priority can also be altered, depending on the user's preference.

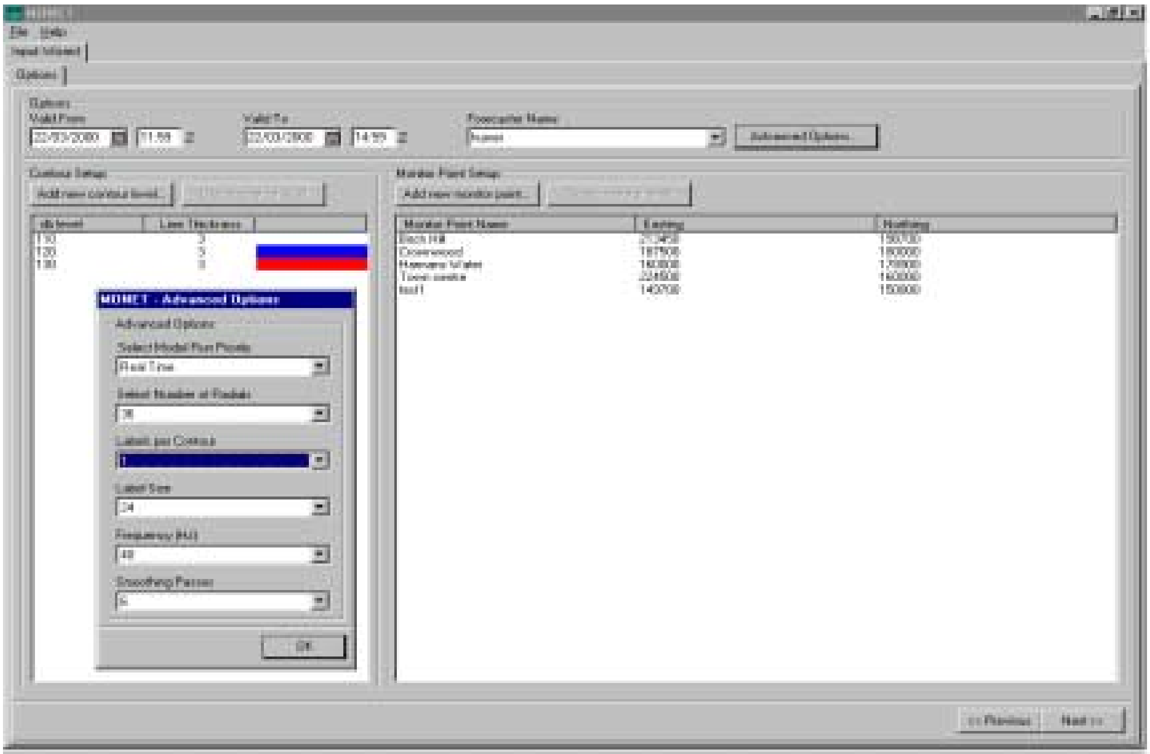


*Figure 5: Options screen*

## 5. <u>Model Output</u>

*Figure 6* shows the sound contour plot and active toolbar. The contour plot, peak sound pressure levels in decibels, is superimposed onto the background map. The map area can be scaled and zoomed in on areas of specific interest. This particular plot detects focusing areas due to the reflection by the acoustically hard water surface.

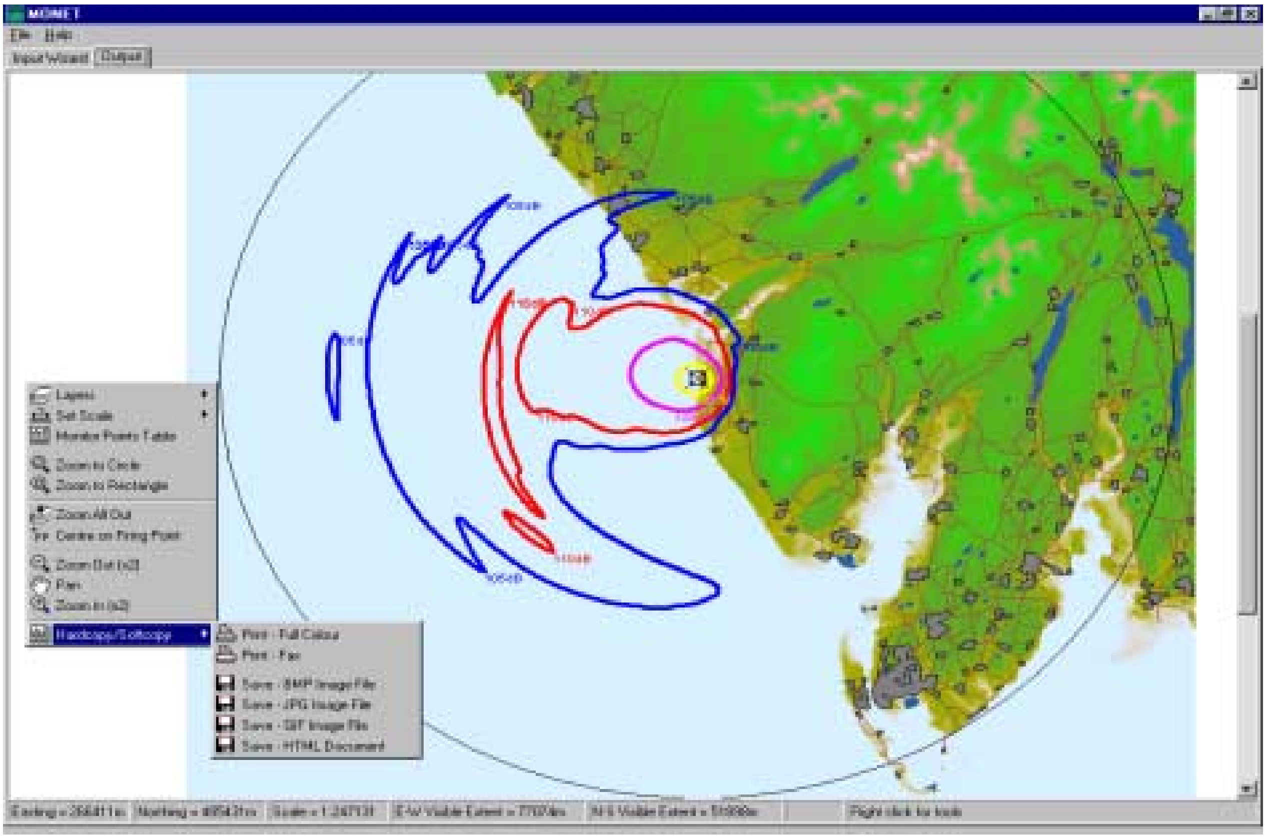


*Figure 6: Output screen*

The active toolbar shows the save options. This determines the delivery format of the plot to the customer by either fax or e-mail.

## 6. <u>Validation</u>

MONET was successfully verified against analytical results produced by DAMTP, Cambridge University, before comparison against field trials. For a description of the theoretical tests consult Horgan[3]. Measurements from four field trials were used to verify MONET. The error in all trials was calculated from model prediction minus actual sound measurement. This error was then compared to the APP's error for the same firing. The total rms error for each trial firing is shown in table 1. Consult the reference[4] for further descriptions of each individual trial.

| Trial | Location | APP rms | MONET rms |
|---|---|---|---|
| 1 | Aberporth, Wales | 14.17 | 6.19 |
| 2 | Aberporth, Wales | 9.68 | 4.32 |
| 3 | Lulworth, England | 5.13 | 8.57 |
| 4 | Shoeburyness, England | 2.83 | 6.18 |
| Overall | Average (rms) | 7.95 | 6.32 |

*Table 1: Verification results*

MONET has clearly the superior results for trials 1 and 2, but shows an uncharacteristic rms error value of 8.57 for trial 3. The APP also fairs better in trial 4. However overall MONET has the higher accuracy.

So why the problem with the third and fourth trial? The Lulworth trial, number three, used several gun types including 120mm Chieftan tank, 105 and 165 mm Centurion tank, 76mm Scorpion tank and Howitzer FH70. Some of these guns are not listed in MONET's weapon choices, so the gun firings were normalised to a 3 kg PE 4 charge weight and the correction for each individual gun type added. It is here that an incorrect conversion from gun to explosive source may have produced the irregular results for trial 3. Indeed a raised barrel from a Chieftain tank will increase the detonation height. The equivalent PE 4 charges were modelled on a surface explosion. Such an initial change at the source will effect the onward propagation. Further field trials on particular guns needs to be carried out so that the sound signature of a specific gun system can be recorded.

This explains the poor performance in the third trial but does not apply to the fourth trial as this involved only plastic explosive testing. In this trial the APP attains a remarkable 2.83 error value and MONET a value of 6.18, close to the mean value. It is believed the terrain of the Shoeburyness trial suited the ray tube theory approach since the area concerned is an estuary and typically flat. MONET can handle any terrain whether flat or varying so surely the parabolic version should still produce better results with its ability to include interference of sound waves? However it seems in this case that MONET's strength has caused the model to over predict in upwind areas. All terrain is seen as totally reflecting, so sound will reflect positively off the surface, whether in reality it is mud flat or grassland, and cause excessive interference. Further releases of MONET will address the problem of varying ground texture. However it looks promising that the ground effect is sensitive at this stage.

## 7. Future work

Further work on MONET is planned over the next year. The Model will be able to take into account varying surface reflection coefficients. These will represent differing land surface textures, i.e., trees, vegetation, water. Presently MONET is set at totally reflecting for all surfaces. Clearly this is not realistic, as each surface is acoustically unique; this weakness was identified by the Shoeburyness trial.

The single upper-air sounding will be enhanced with range-dependent meteorology. Currently the single met. profile is used for propagation out to 30 km. The representation of turbulence and its effect on sound propagation will also be introduced.

This further work applies to the continued use of MONET to model noise nuisance. However further applications can be explored especially in the military arena. Gun location and helicopter noise detection are possible avenues of research.

## 8. Conclusions

The release of MONET has brought a powerful decision aid to Met. Office outstations. Its scientific advantages are coupled with the practical requirements of a fast, accurate and easy to use tool. Verification has shown that MONET and the parabolic equation approach supersede the APP with its ray tube theory. Further work on the second stage of the model will address the noted variations and strengthen the model as a whole.

With pressure on meteorologists to have an increased sense of business awareness, MONET offers an attractive package to customers. It further advances Met. Office commitments to the military regarding noise pollution and opens other potential military uses.

## 9. References


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2. Macaskill, C., Ewart, T. E., Computer Simulation of Two-dimensional Random Wave Propagation. *IMA Journal of Applied Mathematics*, **33**, 1-15, 1984.

3. Horgan, R.R., Tests of 1+1 wave propagation model. D.A.M.T.P., Cambridge University, May 1999.

4. Hume, R.B., Newton, P., Watkins, I.C., MONET 1.0 User Guide. *The UK Meteorological Office, Bracknell.* March 2000.



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