RECENT DEVELOPMENTS IN MICROWAVE AND MILLIMETRE WAVE CLEAR-AIR PROPAGATION FORECASTING

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INTRODUCTION

The forecasting of propagation conditions in the troposphere is important for civil and military communications and radar systems. For microwaves and millimetre waves, clear-air superrefraction and ducting due to variations in meteorology in the lower troposphere are difficult to predict. There are two problems. Firstly, the state of the troposphere must be characterised to sufficient accuracy. Secondly, a propagation model is required that uses these measurements as fully as possible.

Vertical refractive index profiles are usually derived from radiosondes measurements of pressure, temperature and humidity. Older systems were only capable of identifying the thickest ducting layers due to their poor vertical resolution and thermal lags, and required large balloons to use. The new generation of portable minisondes have much better response times and can be operated virtually anywhere. Much needed information on the horizontal variability of refractive index can now be obtained easily from multiple radiosonde ascents. Little work has been done on this aspect of the problem since, until recently, propagation models were not capable of making use of this two-dimensional data.

Forecasting models have mainly been based on ray tracing methods, or on full-wave mode theory techniques. Ray tracing can give reasonable qualitative pictures of the electromagnetic field, but quantitative results are expensive and difficult to automate. Quantitative results are obtained from mode theory, but a general solution for an arbitrary refractive index structure is virtually intractable. Most implementations restrict the refractive index to be a simple analytical function of height alone. The development of the parabolic equation solution to Maxwell's equations has led to a significant advance in propagation modelling in the troposphere.

PARABOLIC EQUATION

The parabolic equation makes use of the fact that horizontal gradients of refractive index in the troposphere are always small. The derivation from the wave equation will not be given here, but can be found in Ko et al [1] and Craig [2]. (See also Craig and Levy [3] for references to an analogous problem in underwater acoustics, on which the current work in the troposphere is based).

In contrast to mode theory, the parabolic equation retains full two-dimensional refractive index information, and unlike ray methods, it retains all the diffractive effects associated with the refractive index structure. The reduction from the elliptic form of the wave equation to the parabolic form is very significant, and gives rises to an efficient numerical implementation. The main limitation of the current model (in common with mode methods) is that the Earth's surface is assumed to be smooth; the model is aimed at applications where the effects of the medium dominate (e.g. transhorizon propagation at microwave frequencies) or for propagation over the sea, rather than for surface diffraction problems at VHF/UHF.

The parabolic equation method has been implemented on a desk-top PC system (Craig and Levy [4]), and can be used at frequencies as high as 100 GHz. Although computation times increase with frequency and range, typical execution times are of the order of a few minutes. Some of the features of the model are:

- colour two-dimensional field strength diagrams are produced directly, giving a better indication of the effects of anomalous propagation than can be obtained from path-loss curves;
- two-dimensional refractive index structures can be modelled analytically or numerically from experimental data;
- antenna radiation patterns are easily incorporated;
- surface impedance and surface roughness effects on interference "lobing" are included;
- gaseous absorption effects are modelled: the absorption at a particular frequency can be calculated at each point from the pressure, temperature and humidity. This is important at millimetre waves where the large absorption coefficients and rapidly varying humidity within ducting structures can give rise to complex field patterns.

APPLICATIONS

Figure 1 shows the field radiated by a 3 GHz antenna located close to an elevated ducting layer. The refractive index structure is based on three radiosonde ascents made along a line from Northern Europe to the UK. The layer height dropped from 800 m to 600 m along the path, the duct thinning and weakening at the same time. The high signal levels at long range are apparent, as is the significant "leakage" from the top of the duct. This leakage is not present when a homogeneous model of the duct is used. The mechanisms by which energy couples into, and out of, a duct are important for an understanding of transhorizon propagation. One-dimensional mode methods do not address this problem adequately, and generally underestimate the field outside the duct.

Figure 2 shows the effect of a 20 m evaporation duct over the sea on a 10 GHz radar at 15 m. The lobing structure is severely distorted, and long range coverage near the surface is possible. (A flattened Earth display is used since the large range–height ratio of the display makes a 4/3 Earth display impractical. In standard conditions the horizon would be at 16 km, and most of the picture would be deep within the diffraction zone.)

The efficiency of the method has opened up new areas of study. One application is the calculation of the effects of propagation on wideband systems. By generating two-dimensional path loss diagrams at a set of frequencies over the bandwidth of interest, wideband channel transfer functions can be calculated at each point in space [3]. The effects of space diversity are easy to evaluate.

Another important application is the calculation of confidence limits on field strength forecasts based on limited or noisy data. Statistical ensembles of field strength diagrams are easily generated and the parameters of the statistical distributions extracted (Levy and Craig [5]).

CONCLUSIONS

Because of its generality and efficiency, the parabolic equation is likely to displace mode and ray methods for the modelling of clear-air propagation in the troposphere. It is effective both for long range propagation caused by elevated ducts, and in the calculation of the effects of low level structures on the lobing patterns of antenna systems. More complex problems, such as wideband effects, can be tackled. The main limitation now is the difficulty of obtaining high quality meteorological data in the first place. The new generation of minisondes should lead to improvements here.

REFERENCES

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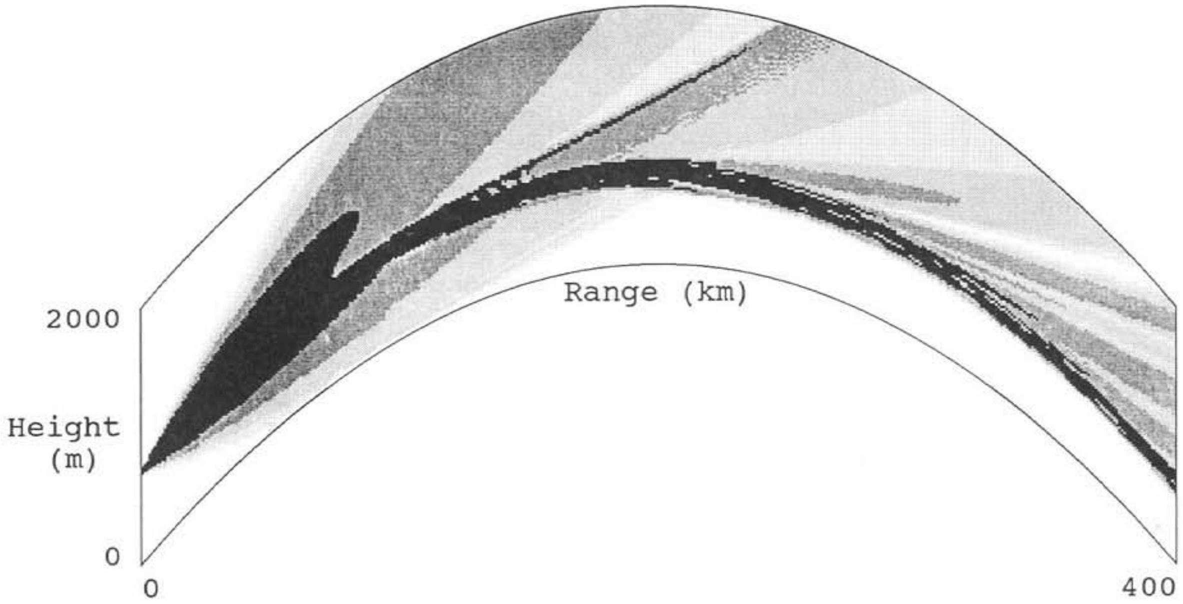

Figure 1: Field radiated by a 3 GHz antenna located close to an inhomogeneous elevated ducting layer. (Contours are at 10 dB intervals).

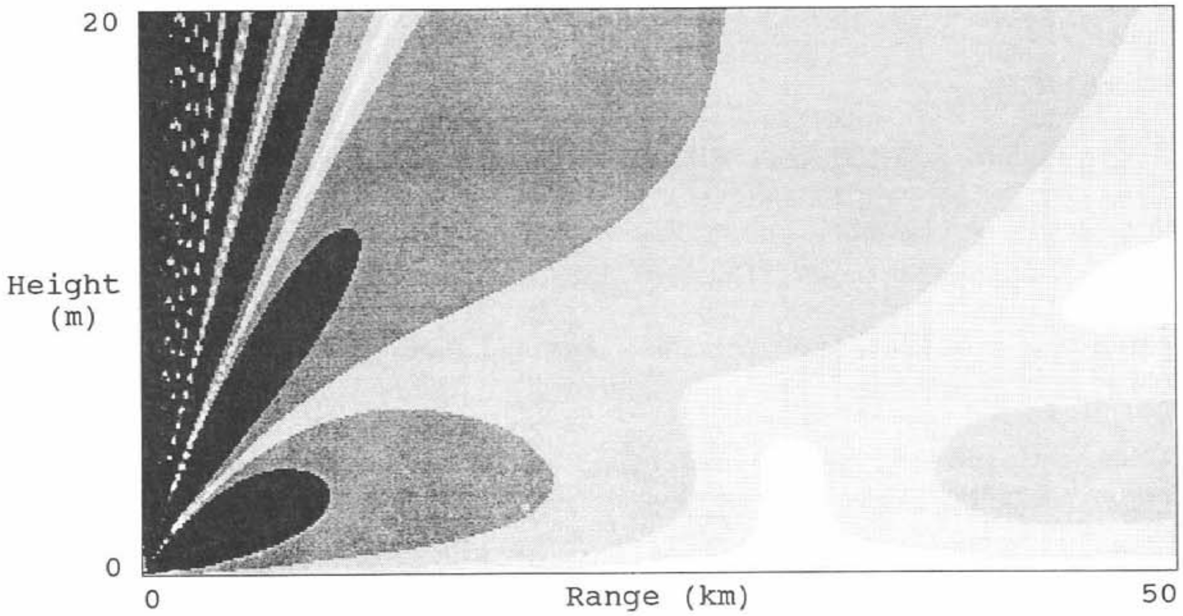

Figure 2: Field radiated by a 10 GHz radar at 15 m, located within a 20 m evaporation duct. (Contour are at 10 dB intervals).