Good Practice Guide
for
Atmospheric Dispersion Modelling

Prepared by the National Institute of Water and Atmospheric Research, Aurora Pacific Limited and Earth Tech Incorporated for the Ministry for the Environment

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Foreword by the Ministry

The introduction of the national environmental standards later this year will see heightened public awareness of air quality issues. Driven largely by a strong need for action on ambient levels of particles in most parts of the country, the standards lay the foundation for an effective air quality management framework. Atmospheric dispersion modelling is an essential tool in air quality management by providing the link between environmental effects and discharges to air. Its use has grown rapidly in New Zealand over the past 10 years and models are now commonplace in many resource consent applications for discharge permits.

Dispersion modelling is a complex process and, as with all models, the results are only as useful as the model itself and how it is used. Many different approaches to modelling have emerged in New Zealand under the Resource Management Act 1991, and at times models have been used incorrectly, causing problems such as inaccurate data, which can mislead an assessment of environmental effects. These issues often delay the processing of resource consents, and can result in expensive hearings where experts argue over the merits of their preferred models and how they should be used.

In a first step to resolving such issues, this draft guide provides expert and well-debated guidance on dispersion modelling through a series of recommended protocols. To improve consistency and accuracy in modelling, the guide is reasonably prescriptive, but the recommendations are not regulatory requirements so there is flexibility to handle the wide variety of circumstances that occur in New Zealand. Deviations from the recommended approaches can be taken, although these should be clearly explained and justified.

Correct interpretation of modelling results against the national environmental standards and determination of the potential effects of a discharge are as important as accurate modelling results. This guide does not include guidance on interpreting results. Instead, this will be included in a *Good Practice Guide for Assessing Discharges to Air* (currently under development by the Ministry).

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Executive Summary

The purpose of this guide is to provide good-practice protocols for modelling the dispersion of discharges to air from industrial complexes in New Zealand. Guidance is provided for all modellers, from relative newcomers to experts. The guideline provides recommendations which direct modellers towards adopting a best practice approach. The recommendations are somewhat prescriptive, but allow flexibility. They are consistent with current practice in Australia and the USA, with some adaptation for New Zealand-specific conditions. The practitioner should always justify the methods used, whichever modelling approach is taken.

For convenience, dispersion model types are divided broadly into steady-state Gaussian-plume models and 'advanced' models. This is a differentiation on roughly historical grounds: plume models have been in common use for decades, while advanced models are beginning to be used more widely for regulatory applications. From a practical standpoint, the greatest difference between model types is in the requirements of meteorological information and computer resources. However, some 'steady-state' models are highly sophisticated and not necessarily 'Gaussian', so the distinction can be blurred. Although the guide encourages modellers to move towards advanced models – because in principle they are more realistic – it does discuss the advantages and limitations of *all* model types. The use of an 'advanced' model need not be the best option.

This guide provides useful guidance for the modeller by discussing specific models currently in use in New Zealand. The list includes AUSPLUME, ISCST3, AERMOD, CTDMPLUS, CALPUFF and TAPM. Model configuration, data requirements, model applicability, physical and chemical formulations and the interpretation of results are discussed for these models.

Much of the guide is devoted to practical advice and provides recommendations on the aspects of dispersion modelling essential to a realistic assessment using a dispersion model. These aspects are the choice of input parameters, the specification of emissions and meteorology, and the analysis of results.

A chapter on model configuration discusses model domain size and receptor distribution, dispersion parameters, stability class specification, the use of turbulence measurements, settings for plume rise and inversion penetration, land-use variations and averaging times. It also describes how the different models simulate emissions from different source types, and provides guidance on emission factor databases and on accounting for time-varying emissions. It further describes how the models simulate the interaction between pollutant plumes from different sources within an industrial complex, in terms of building wake effects and enhanced plume buoyancy.

The simulation of terrain effects on pollutant dispersion is examined in detail, including a description of methods used by the main models.

There is some discussion on atmospheric chemistry – a common requirement is the determination of NO_2 concentrations, given emissions of NO_x. A couple of empirical methods for this are described, although the guide does not favour one over the other.

A complete chapter of this guide is devoted to the meteorological aspects of dispersion modelling. The complex terrain of New Zealand, and the coastal location of most settlements, can lead to highly complicated meteorological features in the vicinity of many pollutant sources. These include land–sea breezes, slope–valley flows and internal boundary layers (with associated fumigation effects), which may cause complex patterns of pollution dispersion.

A fundamental difference between steady-state and advanced models is in their meteorological data requirements. The development of single-site meteorological data for steady-state dispersion models is discussed, including screening data sets, the treatment of calms, missing data, and the derivation of parameters such as stability class and mixing height. The development of three-dimensional time-dependent meteorological data sets for advanced dispersion models using prognostic and diagnostic models is also discussed in detail. The advantages and limitations of all approaches are examined.

Guidance on the analysis of model results is given, to ensure that results are realistic and credible. This includes model validation, assessment of uncertainties and sensitivity tests. Advice is given on the presentation of statistical summaries, tables, graphs and contour plots at the reporting stage. There is also guidance on the incorporation of background concentrations and the assessment of environmental and health effects.

The good practice guide focuses mainly on discharges from industrial sources, but there is some discussion on other specialised applications, such as airshed modelling, dispersion from roadways, regional and long-range transport, accidental releases, steam effects and visibility. Many of the recommendations regarding industrial discharges apply equally to these other cases.

The guide attempts to be forward thinking by acknowledging that dispersion modelling requirements (that is, new applications) and the models themselves are changing, and by providing guidance on the use of the latest, state-of-the-science dispersion models.

1 Introduction

1.1 Aims and objectives

The purpose of this Guide is to provide good practice protocols for carrying out atmospheric dispersion modelling in New Zealand. Where the recommended protocols are not suitable for the particular modelling exercise, the reasons for deviating from them should be clearly explained. In establishing these good practice protocols, the guide aims to improve the use of models in New Zealand and consequently the accuracy of modelling results so they can be relied upon when considering the potential adverse effects of a discharge to air.

The Guide contains information and recommended protocols on many aspects of modelling including: the main types of model available and when to use them, the nature of input data required, and how to get the most accurate results for the level of assessment required. It is designed to assist those relatively new to modelling who may have taken a course or two, and those involved in reviewing modelling outputs for auditing resource consent applications. The 'recommended protocol' shaded boxes should also be useful for expert modellers who are seeking better consistency in how models are used in New Zealand.

It should be recognised that modelling is a complex process and that some training in the form of workshops or courses is advisable before commencing modelling. This Guide will assist in recalling the training you have received and it sets specific protocols to follow where alternative options are available.

The Guide focuses on how to get accurate data once the decision to model has been made. Guidance on when to model and how to interpret modelling results, in terms of evaluating the potential effects of the discharge on the environment, will be contained in a separate document currently being prepared by the Ministry entitled the *Good Practice Guide for Assessing Discharges to Air*. Although these two areas are integrally linked they have been separated to avoid excessive complexity in one document. However, both guidance documents should be reviewed when assessing a discharge to air using dispersion modelling.

Once the decision to model has been made, the Guide can help practitioners to determine:

- which model is most appropriate for the particular circumstances
- what data to put into the model (including emissions data and meteorological data)
- how to run a model effectively
- pitfalls to watch out for
- how to understand the accuracy of modelling results.

The Guide also discusses the advantages and limitations of:

- current practice associated with using steady-state dispersion models as an assessment tool
- new generation models.

The Guide mainly covers the use of dispersion models to assess the effects of pollutants discharged from point (and multiple point) sources. However, modelling of area and line sources is also briefly considered.

Throughout the Guide modellers are encouraged to:

- use the best available information
- comply with the recommendations made in this document and consider applying the guidance
- create an auditable trail of the work undertaken.

The guidance is not intended to replace the detailed user manuals that accompany each dispersion model and these should still be consulted. In addition it should be recognised that the recommendations do not have any regulatory status and they can be deviated from as required and when justified. Neither is the advice in any way government policy.

1.2 Overview

Here is an outline of the information contained in the Guide.

Section 1	(this section) presents the background information that puts atmospheric dispersion models into a wider context and highlights the issues that should be considered before using them.
Section 2	contains a brief review of the Gaussian-plume and advanced models that are commonly used for regulatory applications.
Section 3	contains a brief review of the more specialised applications of dispersion modelling.
Section 4	details processes for determining information that should go into an atmospheric dispersion model to ensure good quality information is obtained.
Section 5	details the importance of, and methods for, acquiring reliable and representative meteorological input for air quality modelling purposes. The meteorological requirements of advanced dispersion models are described and methods by which these requirements can be met are discussed.
Section 6	describes how to present and explain modelling results clearly and simply, including the interpretation of modelling results and addressing the uncertainty in model predictions.

1.3 What is an atmospheric dispersion model?

A model is a simplified picture of reality. It doesn’t contain all the features of the real system but contains the features of interest for the management issue or scientific problem we wish to solve by its use. Models are widely used in science to make predictions and/or to solve problems, and are often used to identify the best solutions for the management of specific environmental problems.

Models may be:

- physical – a scaled-down representation of reality
- mathematical – a description of the system using mathematical relationships and equations.

Contaminants discharged into the air are transported over long distances by large-scale air-flows and dispersed by small-scale air-flows or turbulence, which mix contaminants with clean air. This dispersion by the wind is a very complex process due to the presence of different-sized eddies in atmospheric flow. Even under ideal conditions in a laboratory the dynamics of turbulence and turbulent diffusion are some of the most difficult in fluid mechanics to model. There is no complete theory that describes the relationship between ambient concentrations of air pollutants and the causative meteorological factors and processes.

An atmospheric dispersion model is a:

- mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere
- means of estimating downwind air pollution concentrations given information about the pollutant emissions and nature of the atmosphere.

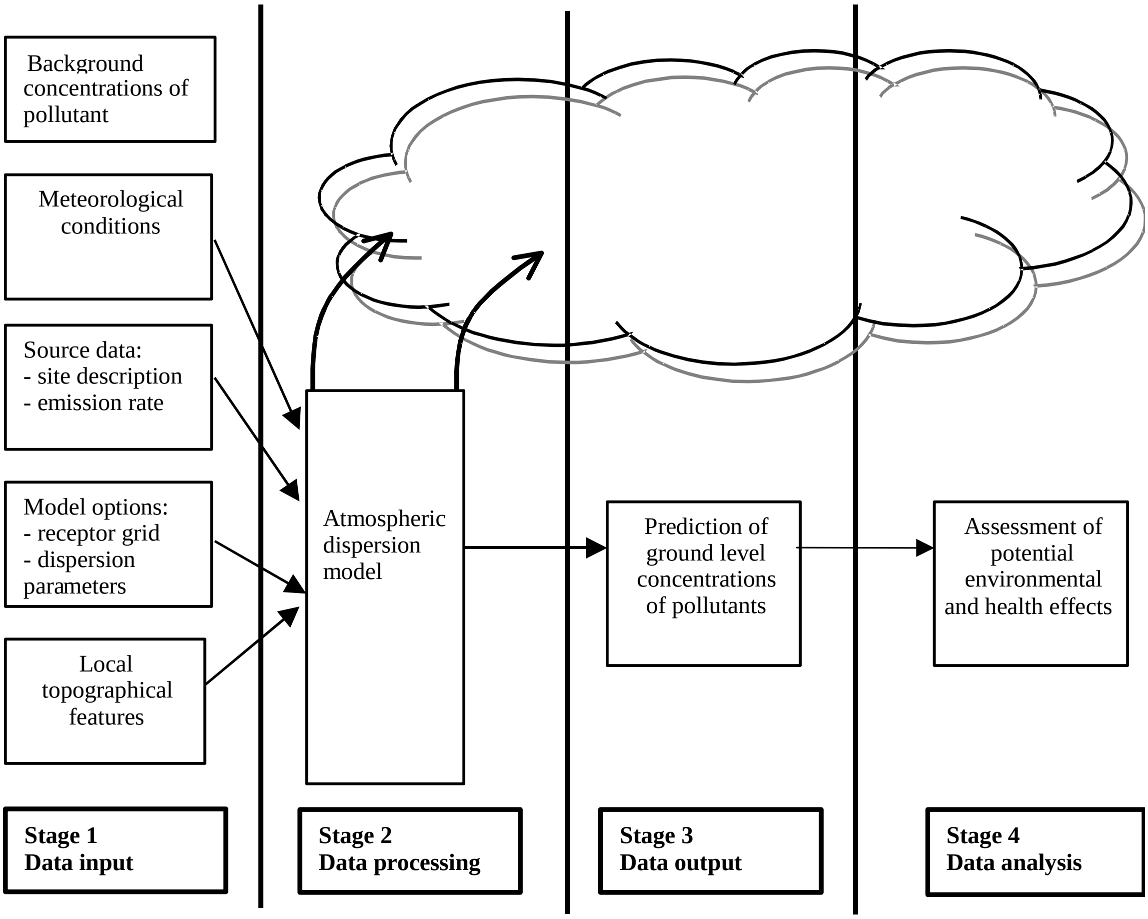
Dispersion models can take many forms. The simplest are provided in the form of graphs, tables or formulae on paper. Today dispersion models more commonly take the form of computer programs, with user-friendly interfaces and online help facilities.

Most modern air pollution models are computer programs that calculate the pollutant concentration downwind of a source using information on the:

- contaminant emission rate
- characteristics of the emission source
- local topography
- meteorology of the area
- ambient or background concentrations of pollutant.

A generic overview of how this information is used in a computer-based air pollution model is shown in Figure 1.1.

Figure 1.1: Overview of the air pollution modelling procedure



The process of air pollution modelling contains four stages (data input, dispersion calculations, deriving concentrations, and analysis). The accuracy and uncertainty of each stage must be known and evaluated to ensure a reliable assessment of the significance of any potential adverse effects.

Currently, the most commonly used dispersion models are steady-state Gaussian-plume models. These are based on mathematical approximation of plume behaviour and are the easiest models to use. They incorporate a simplistic description of the dispersion process, and some fundamental assumptions are made that may not accurately reflect reality. However, even with these limitations, this type of model can provide reasonable results when used appropriately.

More recently, better ways of describing the spatially varying turbulence and diffusion characteristics within the atmosphere have been developed. The *new generation* dispersion models adopt a more sophisticated approach to describing diffusion and dispersion using the fundamental properties of the atmosphere rather than relying on general mathematical approximation. This enables better treatment of difficult situations such as complex terrain and long-distance transport.

Sections 2 and 3 provide detailed descriptions of the different dispersion models available, what each model can potentially be used for, and their benefits and problems.

1.4 The importance of meteorology

The ground-level concentrations resulting from a constant discharge of contaminants change according to the weather (particularly the wind) conditions at the time. Meteorology is fundamental for the dispersion of pollutants because it is the primary factor determining the diluting effect of the atmosphere. Therefore, it is important that meteorology is carefully considered when modelling.

The importance of, and methods for, acquiring reliable and representative meteorological input for air quality modelling purposes are detailed in section 5.

1.5 What can dispersion modelling be used for?

Models can be set up to estimate downwind concentrations of contaminants over varying averaging periods – either short term (three minutes) or long term (annual). In New Zealand, the most common use of dispersion modelling is to assess the potential environmental and health effects of discharges to air from industrial or trade premises. Such assessments are required to be undertaken in accordance with the Resource Management Act 1991 (RMA) for applications for discharge permits. Models are particularly valuable for assessing the impacts of discharges from new activities and to estimate likely changes as a result of process modifications.

Modelling results can also be used for:

- assessing compliance of emissions with air quality guidelines, criteria and standards
- planning new facilities
- determining appropriate stack heights
- managing existing emissions
- designing ambient air monitoring networks
- identifying the main contributors to existing air pollution problems
- evaluating policy and mitigation strategies (e.g. the effect of emission standards)
- forecasting pollution episodes
- assessing the risks of and planning for the management of rare events such as accidental hazardous substance releases
- estimating the influence of geophysical factors on dispersion (e.g. terrain elevation, presence of water bodies and land use)
- running 'numerical laboratories' for scientific research involving experiments that would otherwise be too costly in the real world (e.g. tracking accidental hazardous substance releases, including foot-and-mouth disease)
- saving cost and time over monitoring – modelling costs are a fraction of monitoring costs and a simulation of annual or multi-year periods may only take a few weeks to assess.

1.6 What can't dispersion models do?

Even the most sophisticated atmospheric dispersion model cannot predict the precise location, magnitude and timing of ground-level concentrations with 100% accuracy. However, most models used today (especially the US EPA approved models) have been through a thorough model evaluation process and the modelling results are reasonably accurate, provided an appropriate model and input data are used.

Errors are introduced into results by the inherent uncertainty associated with the physics and formulation used to model dispersion, and by imprecise input parameters, such as emission and meteorological data. The most significant factors that determine the quality and accuracy of the results are:

- the suitability of the model for the task
- the availability of accurate source information
- the availability of accurate meteorological data.

The causes of model uncertainty and the methods by which they should be addressed when using dispersion models are discussed in more detail in section 6.2.

1.7 When is it appropriate to use dispersion modelling as an assessment tool?

Atmospheric dispersion models may not always be the most appropriate method for assessing the potential environmental impacts of a discharge to air. Guidance on when modelling is required as part of an assessment of environmental effects will be covered in more detail in the *Good Practice Guide for Assessing Discharges to Air* currently under development by the Ministry.

Modelling is unlikely to be needed when a discharge is already permitted by a regional plan. However, councils may specify when modelling is required for particular activities. Assessors should consult with relevant councils to determine whether modelling is required before commencing assessments and submitting applications.

Recommendation 1

Before undertaking an assessment of effects using atmospheric dispersion modelling, the proposed approach for assessing adverse effects should be discussed with the relevant council (national guidance will be covered in the *Good Practice Guide for Assessing Discharges to Air* currently under development by the Ministry).

Alternative and perhaps more pragmatic methods of providing information to support assessments should be employed when the scale of the activity is small and its potential environmental effects are likely to be minor, or when modelling is unlikely to provide good-quality information.

Atmospheric dispersion models should only be used when they are appropriate for investigating the scale and significance of the effects of a discharge on the environment, and their use should be justified.

Users must recognise that there are limitations to the scope of a model's application and to the accuracy of model predictions. These should be identified and discussed in conjunction with the modelling results.

Modelling results provide reasonably accurate predictions of ground-level concentrations of contaminants from a discharge, provided input parameters are appropriate. Factors influencing their accuracy should be estimated, reported and acknowledged.

2 Which Dispersion Model To Use?

One of the key elements of an effective dispersion modelling study is to choose an appropriate tool to match the scale of impact and complexity of a particular discharge. When choosing the most appropriate model the principal issues to consider are:

- the complexity of dispersion (e.g. terrain and meteorology effects)
- the potential scale and significance of potential effects, including the sensitivity of the receiving environment (e.g. human health versus amenity effects).

For regulatory purposes in New Zealand, there are two general types of dispersion models that can be used:

- Gaussian-plume models such as AUSPLUME, ISCST3 (EPA[1]), AERMOD (EPA[2]) and CTDMPLUS (Perry et al., 1989)
- advanced models such as CALPUFF (Scire et al., 2000a) and The Air Pollution Model (TAPM) (Hurley, 2002).

Figure 2.1 illustrates the types of models typically applied to particular scenarios, depending on their scale and complexity. The width of the band associated with each model type is roughly proportional to the number of modellers currently using that particular type. In medium-complex atmospheric and topographical conditions with relatively simple effects, Gaussian-plume models can produce reliable results. This modelling accounts for the vast majority of dispersion modelling work in New Zealand. In more complex atmospheric and topographical conditions, advanced puff or particle models and meteorological modelling may be required to maintain a similar degree of accuracy. In choosing the most appropriate model it is very important to understand the model's limitations and apply it only to the situations that match its capabilities.

The choice of an appropriate dispersion model is heavily dependent on the intended application. Many of New Zealand's major cities are located within 20 kilometres of the coast and so the majority of air pollution concentrations over urban areas are affected by highly variable coastal airflows. The situation is further complicated by complex topography. In such environments simple Gaussian-plume models may not provide the best results. This is likely to be especially true if pollutants cause effects at distances greater than about 10 kilometres from their source and under fumigation conditions. In these situations an advanced dispersion model may be more suited to the situation and provide better results.

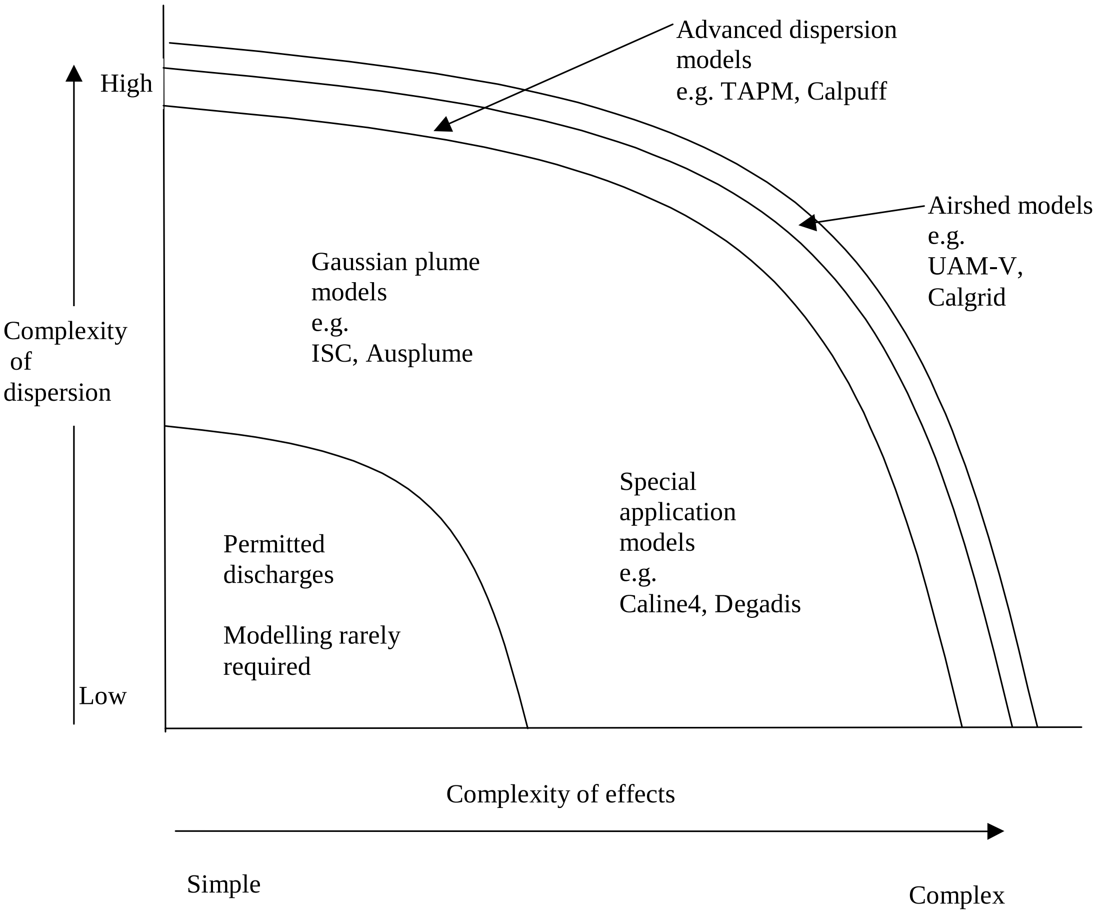
Recommendation 2

To get the best possible results from a dispersion modelling study, the modeller must:

a) choose the most appropriate model for the intended purpose, and

b) justify this choice in the methodology of the study.

Figure 2.1: Type of model typically applied according to the complexity of the problem



In situations of complex terrain or near coastal boundaries, significant changes in meteorological conditions can occur over short distances. Advanced models can simulate the effects of coastal areas and terrain effects on pollutant transport and dispersion in a much more realistic way than a Gaussian-plume model, which assumes spatial uniformity in the meteorology. Clearly this means that advanced models require more detailed meteorological input data to accurately emulate the complex dispersion effects.

Some advanced models are seldom used in regulatory applications due to their complexity, long run-times and inability to model accurately at fine scales. Model developers are attempting to resolve these issues, and advanced models are anticipated to play an increasingly important and more frequent role in the regulatory environment.

Recommendation 3

The following criteria should be used to decide whether to use a Gaussian-plume model or an advanced model.

a) Are you looking at near or far-field impacts?
Plume models are usually only applicable to near-field (within 10 km from the source) calculations. It not wise to assume the meteorology will be the same greater than 10 km away as at the source.

b) Are causality issues important (i.e. the length of time taken for the pollutants to travel from point A to point B)?
Plume models shoot out 'light beams' to infinity and do not take into account the time for the plume to travel from one point to another.

c) Is wet or dry deposition of pollutants likely to be an issue?
There is currently no option to model either wet or dry gas deposition using AERMOD or CTDMPLUS. ISCST3 currently has the same algorithms as CALPUFF for modelling wet and dry deposition of gases and particles. AUSPLUME (5.2) and AERMOD have a crude reflection coefficient algorithm for estimating particle deposition.

d) Do you want to consider SO_x and NO_x chemistry?
The plume models treat SO_x and NO_x chemistry as a simple exponential decay, but do not attempt to address the detailed mechanisms of atmospheric chemistry. Alternatively, they can simulate some chemical processes (e.g. the production of NO_2 from NO_x) as a post-processing step. Advanced models can deal with SO_x, NO_x and organic chemistry, aqueous-phase chemistry and secondary aerosol production.

e) Is your source in a region of complex terrain or a coastal environment?
Meteorology is not uniform in such situations, due to sea breezes or slope and valley flows or other meteorological phenomena. Most Gaussian-plume models do not allow for plume channelling caused by topography. CTDM and ADMS3 are exceptions.

f) Do you suspect inversion break-up fumigation to be an issue?
Most plume models are unable to model inversion-break-up fumigation events. OCD and DISPMOD are exceptions. SCREEN3 can be used for a preliminary assessment of fumigation events.

g) Are stable night-time stagnation events likely to occur?
Gaussian-plume models are unlikely to accurately model stagnation events.

2.1 Gaussian-plume models

Gaussian-plume models are widely used, well understood, easy to apply, and until more recently have received international approval. Even today, from a regulatory point of view ease of application and consistency between applications is important. Also, the assumptions, errors and uncertainties of these models are generally well understood, although they still suffer from misuse.

Gaussian-plume models play a major role in the regulatory arena. However, they may not always be the best models to use and it was noted at the 15th International Clean Air Conference 2000 – Modelling Workshop, that particular models are not always chosen on an objective scientific basis (Ross, 2001).

The Gaussian-plume formula is derived assuming ‘steady-state’ conditions. That is, the Gaussian-plume dispersion formulae do not depend on time, although they do represent an ensemble time average. The meteorological conditions are assumed to remain constant during the dispersion from source to receptor, which is effectively instantaneous. Emissions and meteorological conditions can vary from hour to hour but the model calculations in each hour are independent of those in other hours. Due to this mathematical derivation, it is common to refer to Gaussian-plume models as steady-state dispersion models. In practice, however, the plume characteristics do change over time, because they depend on changing emissions and meteorological conditions. One consequence of the plume formulation is that each hour the plume extends instantaneously out to infinity. Concentrations may then be found at points too distant for emitted pollutants to have reached them in an hour.

Steady-state models calculate concentrations for each hour from an emission rate and meteorological conditions that are uniform across the modelling domain. Thus they simulate hourly-average concentrations. Both Gaussian-plume and advanced modelling are time-varying, changing from hour to hour. The term ‘steady-state’ should not be taken to mean that conditions are steady from hour to hour. The plume formula has the uniform wind speed in the denominator and hence breaks down in calm conditions. It is usual to specify a minimum allowable wind speed for the model.

Recommendation 4

When using a Gaussian-plume model the modeller must be able to demonstrate that, for the situation being modelled, the:

a) limitations inherent in the steady-state formulation are not exceeded (the specific factors that should be considered are detailed in Recommendation 3)

b) technical parameterisations in the plume model adequately treat the situation to be modelled.

Figure 2.2 shows the most common and simple Gaussian-plume approach to dispersion modelling. This describes the bell-shaped (Gaussian) distribution of concentrations in the horizontal and vertical directions.

The Gaussian-plume formula provides a better representation of reality if conditions do not change rapidly within the hour being modelled (i.e. conditions are reasonably steady and do not deviate significantly from the average values for the hour being modelled). The Gaussian-plume representation of dispersion described above is simplistic and, as such, should only be applied under certain conditions.

However, it is impossible to prescribe in advance the exact conditions under which a Gaussian-plume model is applicable. The modeller should initially be guided by the recommendations in this Guide and later by experience. A careful examination of model results should be carried out to determine how realistic the output concentrations are at critical times, given the known geography and meteorology. In this sense, the assessment of model results may be more important than the initial choice of model.

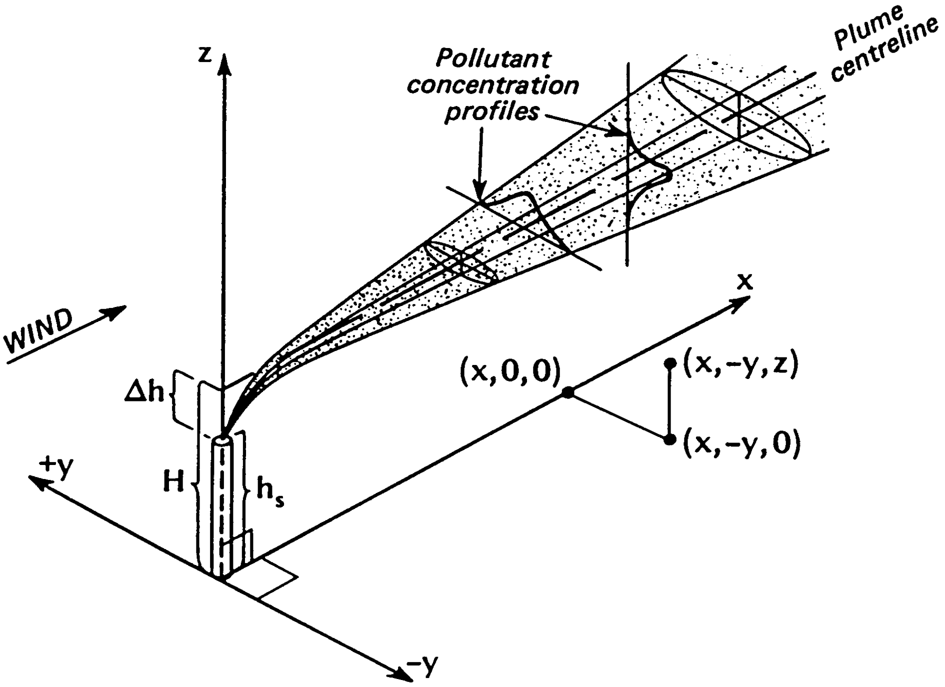
Recommendation 5

Gaussian-plume models are generally applicable when:

a) the pollutants are chemically inert, a simple first-order mechanism is appropriate, or the chemistry may be carried out as a post-processing step
b) the terrain is not steep or complex
c) the meteorology may be considered uniform spatially
d) there are few periods of calm or light winds.

A careful choice of Gaussian-plume model is needed if the effects of deposition, chemistry or fumigation need to be simulated.

Figure 2.2: A typical plume from an elevated point source



Note the plume rise (Δh), and the normal (Gaussian) distribution of pollutant concentrations in the horizontal and vertical (after Oke, 1987).

2.1.1 Common features of Gaussian-plume models

Characteristics of steady-state Gaussian models that make them convenient tools include the fact that they:

- do not require significant computer resources – they can be run on almost any desktop PC and can usually process a complete year of meteorological data in a matter of minutes
- are easy to use – they come with user-friendly graphical user interfaces (GUIs) and a relatively small number of input variables are required
- are widely used – well developed knowledge due to many users and results can easily be compared between different studies
- have simple meteorological data requirements – an input data set can be developed from standard meteorological recordings, and commercially developed data sets are readily available for a number of the metropolitan areas of New Zealand (see Appendix B)
- have conservative results for short (<100 m) or low-level sources – overseas validation shows these models are more likely to over- rather than under-predict ground-level concentrations, which offers some degree of safety in the regulatory environment when assessing discharges from short or low-level sources.

2.1.2 Meteorological data requirements

Although plume models do not have large meteorological data requirements, the meteorology is a crucial component, and good-quality data are needed, ideally from a monitoring site within the area of interest. This is not prohibitively expensive, and is far preferable to using data from a more distant site. This is discussed in detail in section 5.2.

2.1.3 AUSPLUME and ISCST3

Until the last few years, and even currently, AUSPLUME (which was derived from ISCST2) has enjoyed the status of being the de facto standard Gaussian-plume model in New Zealand. ISCST3 is also commonly used in New Zealand, but to a lesser degree than AUSPLUME. Both models are and will remain particularly useful as screening models (which can be used to determine whether more advanced modelling is required or not), and for small, steady-state, near-field applications.

AUSPLUME employs a GUI through which the user may easily edit and execute the model. The model is very easy to use and quick to run, and the output is easily interpreted. The latest version of the AUSPLUME model (version 5.4) has a number of enhancements such as the PRIME building-downwash component.

However, AUSPLUME (and to a lesser degree ISCST3) has been used in some applications without consideration of whether it is the most appropriate model. This is especially true in odour modelling (Godfrey and Scire, 2000) and in other larger-scale, longer-range, complex terrain and non-steady-state-type applications.

AUSPLUME has recently undergone a major re-write. However, despite this upgrading, AUSPLUME (v5) will still be limited in its application because of the fundamental steady-state assumption that it employs.

Despite this widely recognised limitation, AUSPLUME and ISCST3 still enjoy regulatory status in Australia and the United States, respectively.

AUSPLUME and ISCST3 are principally designed for calculating impacts in regions of flat terrain. The more advanced AERMOD and CTDMPLUS are designed for use when complex terrain is an issue. Whether designed for flat or complex terrain, Gaussian-plume models are best used for near-field applications where the steady-state meteorology assumption is most likely to apply.

2.1.4 AERMOD

AERMOD is a ‘near-field, steady-state’ guideline model. It uses boundary-layer similarity theory to define turbulence and dispersion coefficients as a continuum, rather than as a discrete set of stability classes. Variation of turbulence with height allows a better treatment of dispersion from different release heights. Also, dispersion coefficients for unstable conditions are non-Gaussian, to represent the high concentrations that can be observed close to a stack under convective conditions.

AERMOD was developed in 1995, reviewed in 1998 and formally proposed by the US EPA as a replacement for ISCST3 in 2000. However, this status has not yet been achieved and is likely to take some time.

2.1.5 CTDMPLUS

CTDMPLUS is a US EPA regulatory model developed specifically for tall point-sources in areas of complex terrain. CTDMPLUS is a steady-state plume model containing algorithms that enable a more physically realistic description of vertical dispersion and air-flow around complex terrain features. In the past CTDMPLUS has been successfully used in New Zealand, but it is not frequently used any more due to its highly specialised meteorological data requirements and its applicability only to tall point sources. CTSCREEN (EPA4) is a screening version of CTDMPLUS.

2.1.6 Limitations of Gaussian-plume models

The following limitations of steady-state Gaussian models should be considered and weighed up against the advantages before employing this type of model in any dispersion study.

a Causality effects

Gaussian-plume models assume pollutant material is transported in a straight line instantly (like a beam of light) to receptors that may be several hours or more in transport time away from the source. They make no account for the fact that wind may only be blowing at 1 m/s and will only have travelled 3.6 km in the first hour. This means that plume models cannot account for causality effects. This feature becomes important with receptors at distances more than a couple of kilometres from the source.

b Low wind speeds

Gaussian-plume models ‘break down’ during low wind speed or calm conditions due to the inverse wind speed dependence of the steady-state plume equation, and this limits their application. Unfortunately, in many circumstances it is these conditions that produce the worst-case dispersion results for many types of sources. These models usually set a minimum wind speed of 0.5 or 1 m/s and sometimes overwrite or ignore input data below this with this lower limit.

c Straight-line trajectories

In moderate terrain areas, these models will typically overestimate terrain impingement effects during stable conditions because they do not account for turning or rising wind caused by the terrain itself. CTDM and SCREEN are designed to address this issue.

d Spatially uniform meteorological conditions

Gaussian steady-state models have to assume that the atmosphere is uniform across the entire modelling domain, and that transport and dispersion conditions exist unchanged long enough for the material to reach the receptor. In the atmosphere, truly uniform conditions rarely occur. Water bodies, hills and other terrain features, differences in land use, surface characteristics, and surface moisture (e.g. irrigated vs unirrigated agricultural fields) all produce inhomogeneities in the structure of the boundary layer which can affect pollutant transport and dispersion.

Convective conditions are one example of a non-uniform meteorological state that Gaussian-plume models cannot emulate. For tall stacks (>100 m) under convective conditions – overseas studies have shown that under prediction can occur in the near field (Hibberd, 2000 and Luhar and Hurley, 2002). The notable exception to this is AERMOD, which has a specially developed, ‘add-on’ probability density function.

e No memory of previous hour’s emissions

In calculating each hour’s ground-level concentration the plume model has no memory of the contaminants released during the previous hour(s). This limitation is especially important for the proper simulation of morning inversion break-up, fumigation and diurnal recycling of pollutants over cities.

f A potential quick fix

It is possible to overcome some of the limitations of a plume model without using a complete advanced model run. One potential approach is to use single-surface meteorological data (i.e. AUSPLUME/ISC type files with an advanced model). An example of using CALPUFF meteorological data from a single site (‘screening mode’) is given in *Analysis of the CALMET/CALPUFF Modelling System in a Screening Mode* (US EPA 1998). Detailed technical advice on how to run CALPUFF using AUSPLUME/ISCST3 type meteorological files is provided in the CALPUFF manual.

However, it should be pointed out that in this screening mode, the benefits of spatially varying meteorology and complex terrain effects are not being taken advantage of. The screening mode is not recommended by the developers of CALPUFF. They suggest that better-quality results can be achieved using CALMET/CALPUFF run with a proper representation of the terrain and three-dimensional meteorological fields.

Recommendation 6

If a Gaussian-plume model is inappropriate for a particular application because of its limitations, and a full puff model meteorological data set is not available, an advanced model with a single-point meteorological data set should be considered.

2.2 Advanced dispersion models

Although Gaussian-plume models are commonly used in New Zealand for regulatory impact assessments, other less restrictive dispersion models are available. These have been in use for scientific research for decades, and are now beginning to enter the regulatory arena. Their use avoids most of the limitations associated with steady-state models. Although their demands on resources (human, computational and data) are far higher than those of Gaussian-plume models, computer power is also increasing rapidly, making this aspect less of an issue. However, the use of advanced models does involve much greater meteorological input data demands.

Advanced dispersion models may be grouped into three categories depending on the way the air pollutants are represented by the model.

Particles

Pollutant releases, especially those from point sources, are often represented by a stream of particles (even if the pollutant is a gas), which are transported by the model winds and diffuse randomly according to the model turbulence. Particle models are computationally expensive, needing at least 10^5 particles to represent a pollutant release, but may be the best type to represent pollutant concentrations close to the source.

Puffs

Pollutant releases can also be represented by a series of puffs of material which are also transported by the model winds. Each puff represents a discrete amount of pollution, whose volume increases due to turbulent mixing. Puff models are far less computationally expensive than particle models, but are not as realistic in their description of the pollutant distribution. However, they are often more than adequate, and are used for regulatory purposes.

Grid points

Pollutant distributions are represented by concentrations on a (regular) three-dimensional grid of points. This is the cheapest formulation computationally, but difficulties arise when the scale of the pollutant release is smaller than the grid point spacing. This method is commonly used for airshed modelling (section 3.1), and the simulation of chemical transformations is most straightforward in a grid model.

Efforts to increase computational efficiency while still retaining a realistic description of pollutant dispersion mean that many models are a combination of the above-mentioned types. For example, the ‘PARTPUFF’ approach (Hurley, 1994) represents the pollutants as Gaussian puffs in the horizontal and particles in the vertical, particle models usually convert particles to a gridded distribution when the particles have dispersed sufficiently (Lyons et al., 1994), and grid point models often represent sub-grid-scale releases as particles or puffs (Morris et al., 1992).

The fundamental difference between advanced models and Gaussian-plume models is that the advanced models require three-dimensional meteorological fields (see section 4.6) rather than measurements at a single point, and an assumption of spatial uniformity.

There are a number of issues to consider when applying an advanced dispersion model to an air quality assessment. These may deter a potential user, due to the extra investment of effort required, but should lead to more realistic and reliable results. These include:

- a detailed understanding of boundary-layer meteorology, atmospheric turbulence, mesoscale meteorology and (perhaps) atmospheric chemistry and particle dynamics
- a high-specification desktop PC with more memory, disk space and processing time than required for Gaussian-plume models (output files are usually in the order of megabytes and run times can reach hours or days)
- a complex user interface because of more input parameters, which means visualisation of output can also require post-processing software to handle large output files

- an increased risk of model misuse because of the small base of understanding and expertise created by fewer people using advanced models compared to Gaussian-plume models
- a fully three-dimensional, time-dependent meteorological data set is usually required, which needs a good understanding of air pollution meteorology (section 5.3).

However, not all assessments will require a full three-dimensional, spatially varying meteorological data set, and under some circumstances a simple plume model meteorological data set can be used effectively with a puff model run in screening mode. See section 2.1.6(f) for an example of how this may be undertaken.

Recommendation 7

Advanced models should be used when:

a) meteorological conditions vary across the modelling domain and therefore are not compatible with a steady-state model

b) sources or receptors are located in complex terrain, which affects the meteorological as well as the plume-dispersion characteristics

c) pollutants accumulate in calm conditions or are re-circulated as the wind changes direction

d) frequent periods of low wind speed or calms are experienced in the area.

e) chemical transformations between pollutant species are important

f) appropriate meteorological data are available to drive them.

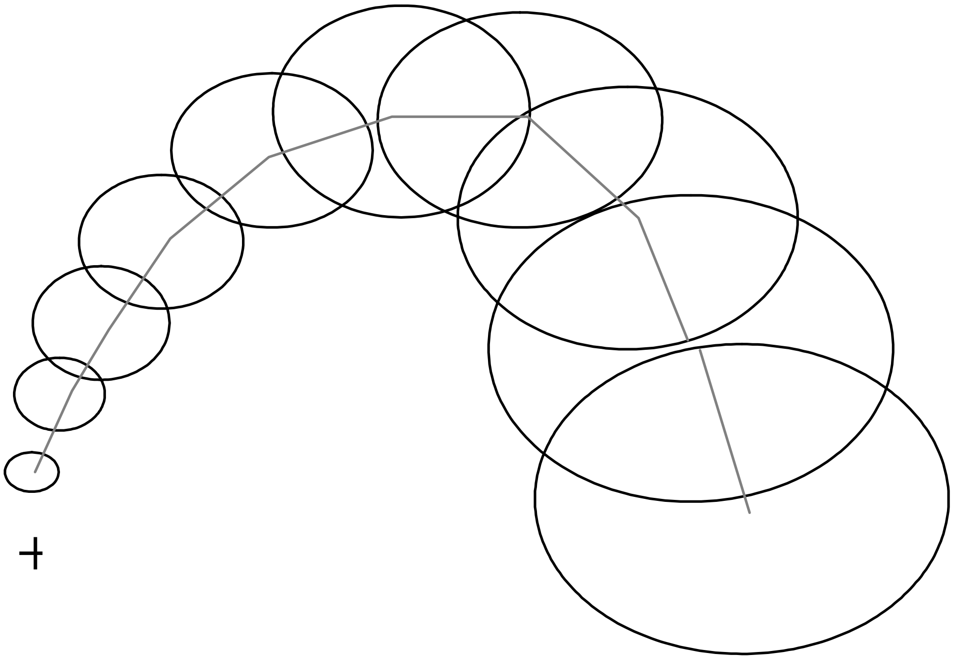
The most commonly used advanced dispersion models in New Zealand are CALPUFF and TAPM.

2.2.1 CALPUFF

CALPUFF (a puff model) has recently been accepted by the US EPA as a guideline model to be used in all regulatory applications involving the long-range (>50km) transport of pollutants. It can also be used on a case-by-case basis in situations involving complex flow and non-steady-state cases from fence-line impacts to 50 km. It is freely available and is the most widely used puff model in New Zealand. For more detailed information and model availability, visit www.src.com/calpuff/calpuff1.htm.

CALPUFF is a multi-layer, multi-species non-steady-state Gaussian puff dispersion model which is able to simulate the effects of time- and space-varying meteorological conditions on pollutant transport (Scire, 2000a). Its puff-based formulation is described in Figure 2.3. This enables the model to account for a variety of effects such as spatial variability of meteorological conditions, causality effects, dry deposition and dispersion over a variety of spatially varying land surfaces, plume fumigation, low wind-speed dispersion, pollutant transformation and wet removal. CALPUFF has various algorithms for parameterising dispersion processes, including the use of turbulence-based dispersion coefficients derived from similarity theory or observations.

Figure 2.3: **Graphical representation of the puff modelling approach**



\+ Release point

The meteorological data for a full CALPUFF run are provided by CALMET, its meteorological pre-processor. This is described in section 5.3.1. However, it is possible to overcome some of the limitations of the plume model without carrying out a full CALPUFF run, as CALPUFF may also be driven by meteorological data from a single site in the same form as the data for AUSPLUME or ISCST3. This overcomes some of the following limitations of the Gaussian-plume formulation:

- the effects of causality will be simulated (i.e. no spot light effect)
- the previous hour's emissions are included
- calm and low wind speeds will be treated more realistically.

2.2.2 TAPM

The Air Pollution Model (TAPM) was developed by scientists at Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) to simulate three-dimensional meteorology and pollution dispersion in areas where meteorological data are sparse, or non-existent (Hurley, 2002). The formulation of TAPM enables it to run quickly, therefore long-term simulations can be carried out on a PC – similar meteorological models generally need fast workstations. The modelling system contains a number of dispersion modules. These include a particle/puff dispersion model for dispersion from point, line, area and volume sources, and a three-dimensional grid-point model for urban air pollution studies. The dispersion models allow for plume rise and building wake effects, and wet and dry deposition, and there is a chemistry module for urban airshed applications. One feature of TAPM is that the meteorological file for the modelling run is created automatically using meteorological information and terrain data supplied for the model. For more detailed information and model availability, visit www.dar.csiro.au/tapm. TAPM's performance has been verified for several regions in Australia, and the model system is being used at several institutions in New Zealand.

The applications that TAPM and CALPUFF are designed for are very similar, as both are intended for regulatory impact assessments (among other things). They are a significant advance on the steady-state Gaussian-plume formulation. Their main difference is in the calculation of the meteorological fields used by the dispersion model. This is discussed further in section 5.3.

2.3 The relative cost of advanced dispersion modelling compared to Gaussian-plume modelling

There is anecdotal evidence to suggest reluctance among practitioners to use advanced dispersion models because of potential additional costs. Cost is an issue that needs to be considered when contemplating which approach to adopt for an assessment. However, it is difficult to compare the different approaches quantitatively because of the number of issues that influence the overall cost of the modelling exercise, which are outlined below.

- **Staff upskilling** – the time and cost involved in this will be more because of the complexity of advanced modelling.
- **The detail of source and site data** – this is similar to other modelling methods.
- **Meteorological and terrain data** – producing a full meteorological data set and terrain file requires more input data and takes more time than for a plume model. There are several options for minimising the cost of this. If the terrain is not complex then it may be possible to produce good results using a plume model meteorological data set. If a full meteorological data set is required, it may be more efficient to purchase a ready-made data set if available. Several organisations are currently developing these data sets. An alternative is to seek independent expertise to produce the required data.
- **Configuring model and processing time** – initially, configuring an advanced dispersion model is likely to take more time because of the large number of variables associated with this type of model. As a modeller becomes familiar with the more complex modelling system, the difference in effort required by the two systems is not likely to be significant. Running an advanced model will take more computer time, but because the models can be run on desktop PCs there is little or no cost difference between running a puff and a plume model.
- **Interpreting and reporting the model output** – all modelling approaches require similar levels of time and cost to interpret and report the model output, and so there is no significant cost difference here.
- **Credibility of results** – this is likely to be regarded more highly, and the cost of processing an industrial assessment of environmental effects (AEE) minimised, if the model is not operating outside the limitations for which it was designed. In circumstances where the use of an advanced dispersion model can produce more credible results, there is likely to be a cost benefit in using that type of model.

Recommendation 8

The potential benefits of producing more credible results should be weighed against the disadvantages (including cost) of using an advanced dispersion model before deciding which approach to take in a particular dispersion study.

2.4 Limitations of advanced dispersion models

Advanced dispersion models are more sophisticated than Gaussian-plume models, and aim to produce more realistic results. Even so, results from advanced models should *not* be automatically assumed to be better than those gained from Gaussian-plume models. One situation where this situation may arise is when a feature that has been added to a plume model (e.g. a building downwash algorithm) is not included in advanced models.

Some other examples where advanced models may do no better than Gaussian-plume models include:

- grid-point models close to a localised source
- near-field receptors under non-convective conditions
- near-field receptors for wind speeds over 1 m/s.

Depending on the situation being modelled, the choice between representating the pollutant release as a plume (i.e. Gaussian-plume models) or a collection of puffs or particles (i.e. advanced models) may be less important than incorporating atmospheric chemistry or deposition or dense gas effects, which a particle model may not include.

The issues that will determine whether or not advanced models will provide more realistic results will vary from case to case. As a starting point, a comparison of the manuals and validation studies of both (or all) the models being considered should provide the modeller with some guidance on whether or not better results could potentially be obtained by using an advanced model.

In summary it is important to:

- remember that results from advanced models should *not* be automatically assumed to be better than Gaussian-plume models
- clearly justify the choice of model being used.