Meteorological Datasets for the Auckland Region – User Guide

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Meteorological Datasets for the Auckland Region – User Guide

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Executive summary

Air dispersion models are frequently used for assessing potential environmental effects that arise from pollutant discharges to air, including industrial sources and land transport projects. Meteorological data are a critical input for these models. In order to provide consistent and robust meteorological data for air discharge assessments, a suite of meteorological datasets has been produced for the Auckland region. They replace previous datasets used in the Auckland region (e.g., 1996 and 1997 AUSPLUME datasets) and those earlier datasets should no longer be used. The purpose of this user guide is to explain how the datasets were developed and provide guidance on their use.

The datasets have been prepared primarily for CALPUFF and for other commonly used air dispersion models in the region. The hourly three dimensional datasets cover the whole region to a 1 km grid resolution, and nine major industrial areas and transport corridors to a 100 m grid resolution with subsidiary meteorological files for AUSPLUME, AUSROADS or CALINE4. CALPUFF and AUSPLUME are typically used for industrial sources while AUSROADS and CALINE4 for land transport applications. Nine high resolution domains are provided for Orewa, North Shore, Waitamata Harbour, Avondale, Penrose/Onehunga, East Tamaki, Mangere, Wiri/Manukau and Papakura. The datasets are for two years, 2005 and 2007, following a review of meteorological and ambient air quality monitoring data. This is to allow for inter-annual variability in meteorological conditions. The table below summarises these datasets.

Table

Summary of meteorological datasets for the Auckland region.

Location	CALPUFF			AUSPLUME, AUSROADS and CALINE4
	Dataset	Size (km x km)	Grid (m)	Dataset
Orewa	H1	9 x 16	100	H1
North Shore	H2	10 x 10	100	H2
Waitemata Harbour	H3	10 x 10	100	
Avondale	H4	10 x 10	100	H4A (Avondale) H4B (Waterview)
Penrose/Onehunga	H5	10 x 10	100	H5
East Tamaki	H6	10 x 10	100	H6
Mangere	H7	10 x 10	100	H7
Wiri/Manukau	H8	10 x 10	100	H8
Papakura	H9	10 x 10	100	H9
Whole region	Reg	105 x 135	1000	

Steps for use of the datasets are outlined as following:

- Obtain the datasets from the Auckland Regional Council (ARC).
- Select an appropriate dispersion model. For industry sources, the preference is for CALPUFF. See Chapter 4 for details about the choice of dispersion models and Chapter 6 regarding recommended CALPUFF settings.
- Select a dataset from those listed in the table above. Refer to Chapter 7 for a summary of recommendations on the use of the datasets.
- Undertake dispersion modelling for both 2005 and 2007, with results presented for each year separately.

The Auckland region contains complex terrain, and experiences complex land-sea breeze interactions and periods of calm or light wind. Advanced dispersion models, such as CALPUFF, can be used to overcome these limitations for large industrial air discharges in Auckland. AUSPLUME, AUSROADS and CALINE4 are steady state Gaussian plume models, which require relatively simple meteorological data from a single location. They are appropriate for near field applications where terrain is not complex, meteorology is spatially uniform and periods of calm or light winds are infrequent.

The meteorological model CALMET was used to generate the datasets. The prognostic meteorological component of TAPM (The Air Pollution Model) was used to provide upper air information for input to CALMET, supplementing the surface based measurements from the meteorological sites.

The outputs from TAPM were checked for realistic flows, such as sea breezes and slope flows. They were also compared with observations from selected meteorological sites, and with the 900 mb, 750 mb and 500 mb pressure levels of the Whenuapai soundings. The results show that TAPM performs well over the Auckland region. The outputs from CALMET were checked for realistic terrain flows and realistic influences of meteorological observations. The results show a good performance for CALMET. Therefore, the meteorological modelling results are realistic and suitable for use for air dispersion modelling in the Auckland region.

Single-point meteorological datasets were extracted from the CALMET outputs for AUSPLUME, CALINE4 or AUSROADS at a representative location chosen from each high resolution domain. The extracted boundary-layer parameters, such as surface wind, stability class and mixing height, were converted into a format compatible with the Gaussian plume models. Some adjustments were made to ensure consistency between the parameters with reasonable, but conservative, dispersion model results.

The datasets are supplied as inputs for CALPUFF and Gaussian plume models, so that complex meteorological models need not be run for air discharge assessments. Input files for CALMET are also provided for information. Meteorological datasets have been produced with CALMET version 6.211. They are compatible with CALPUFF versions 6.112 and 6.262, AUSPLUME version 6.0 and AUSROADS version 1.0. Dispersion modelling should be undertaken for both 2005 and 2007, with results presented for each year separately.

It is expected that the new meteorological datasets will be used for all assessments of discharges to air from industrial sources in the Auckland region. New Zealand Transport Agency (NZTA) should be consulted for the use of the datasets for assessments of discharges to air from transport projects in the Auckland region. In exceptional circumstances (outlined in Chapter 7) the recommended datasets may not be suitable and an alternative dataset may need to be developed. Development of any alternative meteorological datasets for regulatory purposes in the Auckland region in these circumstances should not be undertaken without prior discussions with the ARC for industrial sources or NZTA for transport projects. If an alternative dataset is to be used for a consent application (or notice of requirement for a new or altered designation) a copy of the alternative dataset, together with documentation clearly outlining reasons for the development, methodology, assumptions and the comparison with the recommended datasets, should be provided to the ARC (or the Auckland Council after 1 November 2010) for industrial sources or NZTA for transport projects. The methodology should follow in general the methods as outlined in this guide.

1 Introduction

This user guide provides advice on the use of new meteorological datasets for the Auckland region, and includes information on the methods used in their development.

1.1 Background

A suite of meteorological datasets has been produced for commonly used air dispersion models in the Auckland region, covering major industrial areas and transport corridors. The datasets have been prepared primarily for CALPUFF, with subsidiary meteorological files for use with AUSPLUME, AUSROADS or CALINE4. CALPUFF and AUSPLUME are typically used for industrial applications. AUSROADS and CALINE4 are used for land transport applications.

It is expected that the datasets will be used for air quality assessments of industrial or transport projects in the Auckland region. The datasets are supplied as dispersion model inputs, so that complex meteorological models need not be run to support specific dispersion-model impact assessments. This has the advantage that consistent and accepted meteorological data are used for the assessments.

Meteorological datasets have been produced with CALMET version 6.211 (released 14 April 2006). They are compatible with CALPUFF versions 6.112 (also released 14 April 2006) and 6.262 (released 25 July 2008).

This user guide has been prepared based on the draft report provided by Golder Associates (NZ) Limited (Golder, 2009). Use of the meteorological datasets is subject to the terms and conditions set out in the ARC data release agreement.

1.2 Purpose of this guide

This user guide provides information for each dataset, such as date and location parameters, which are needed by the dispersion models. Information required to use the meteorological data is contained in the main body of this document. Background information on the methodology, and the results of model evaluation studies are contained in the appendices. This document also provides advice on the use of the meteorological datasets.

Several good practice guides (GPGs) have been developed by air quality scientists in New Zealand, and published by the Ministry for the Environment (MfE). These include GPGs for atmospheric dispersion modelling (MfE, 2004b), and for assessing discharges to air from industry (MfE, 2008a) and land transport (MfE, 2008b). The ARC has issued technical guidance on assessing discharges of contaminants into air (ARC, 2002) and New Zealand Transport Agency (NZTA) intends to issue guidance for transport projects (see http://air.nzta.govt.nz/). This document provides some supplementary recommendations, not covered in those guides, but most of the recommendations made here are taken from those GPGs and are therefore consistent with them. The information contained in this guide is intended to reflect current good practice.

1.3 Target readers

This guide is for a broad range of users, including:

- Technical experts, such as environmental consultants, using the meteorological datasets as input to dispersion models, as part of an air quality assessment or AEE;
- Investigating officers, planners or environmental managers of ARC or NZTA, reviewing air quality assessments or resource consent applications which have made use of the datasets;
- Scientific researchers, when carrying out projects relating to ARC or NZTA policy;
- Independent researchers and interested members of the general public.

1.4 Report structure

Chapter 2 contains background information on meteorological and dispersion modelling. Chapter 3 outlines the methodology used for the development of the meteorological datasets (with fuller details in Appendix A). Chapter 4 contains advice on the choice of dispersion model, depending on the type of assessment being carried out. Chapter 5 contains information on the model domains available, including maps and parameter lists for dispersion model input. Chapter 6 contains recommendations on parameter choices in CALPUFF which differ from "default" settings. Chapter 7 summarises recommendations on the use of the datasets.

1.5 Use of the datasets

Steps for use of the datasets are outlined as following:

- Obtain the meteorological datasets from the ARC. NZTA should be included in all correspondence for datasets for transport dispersion models.
- Select an appropriate dispersion model. For industry sources, the preference is for CALPUFF. See Chapter 4 for details about the choice of dispersion models and Chapter 6 regarding recommended CALPUFF settings.
- Select a dataset from those for nine major industrial areas and transport corridors. Refer to Section A.5.4.4 (Appendix A) for use of datasets for transport dispersion models and Chapter 7 for a summary of recommendations on the use of the datasets. Datasets for CALPUFF are monthly files of approximately 2 Gigabyte

(GB) each. CALMET input files are available if required. There are two datasets for steady state models, each for 2005 and 2007.

- Undertake dispersion modelling for both 2005 and 2007, with results presented for each year separately.

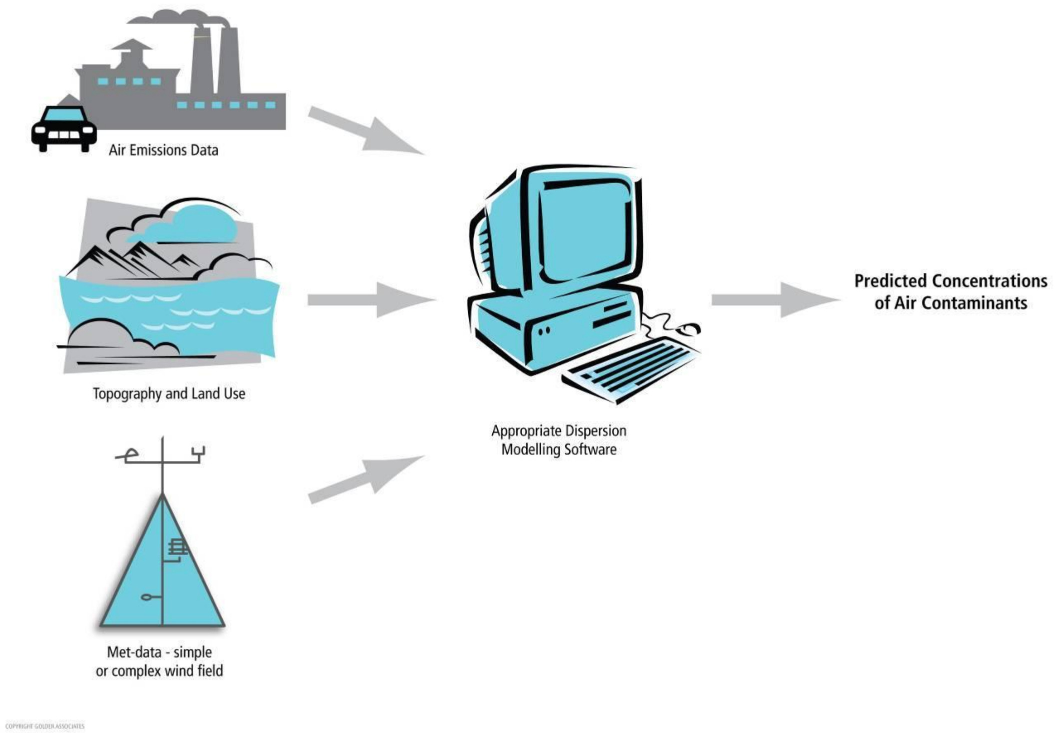
The terms and conditions for use of the meteorological datasets are set out in the ARC data release agreement. Briefly, datasets are provided for use in dispersion modelling for assessment of air discharges in Auckland. ARC, NZTA and Golder Associates (NZ) Limited expressly disclaim all liability for any damage or loss resulting from the use of, or reliance on the information and data that are provided on an "as is" basis.

2 Air dispersion models and meteorological data

2.1 Air dispersion models

Air dispersion models are computational tools used to calculate air pollutant concentrations downwind of an emission source, or concentration variations within an airshed due to the cumulative effects of different sources. They require information on the contaminant emission rate, other characteristics of the source, the local topography and meteorology of the area, and in some situations ambient or background concentrations of pollutants. A schematic of the dispersion modelling process is shown in Figure 2.1.

Figure 2.1
Conceptual illustration of air dispersion modelling, including the role of meteorological data.



Air dispersion models are frequently used as a tool for assessing potential environmental effects that arise from pollutant discharges to air. The key advantage of dispersion modelling is that detailed predictions of contaminant concentrations may be made over a wide area, as a supplement to (or instead of) ambient monitoring or other methods, which are usually only available at isolated locations (or for industries already in operation).

Air dispersion modelling has been frequently carried out to assess the air quality impacts of industrial point sources in Auckland, often as part of resource consent applications for industrial discharges. Dispersion modelling assessments for land transport projects have also been undertaken. In addition, a specific type of dispersion modelling, urban airshed modelling, has been in progress over the last decade for scientific research and to aid urban air quality management.

2.2 Meteorological data

Contaminant concentrations predicted by a dispersion model are dependent on the meteorology of an area, and the source characteristics. The meteorology determines how a contaminant plume disperses and dilutes in the atmosphere as the plume moves away from its source. The most important meteorological elements are wind direction and speed (for pollution transport), and turbulence and mixing in the boundary layer (for pollution diffusion).

Until now, the dispersion models most commonly used for applications in the Auckland region have been steady state Gaussian plume models, such as AUSPLUME and ISCST3. These models have relatively simple meteorological data requirements, and electronic files could be obtained from the ARC. The meteorological datasets were produced for only two locations (Auckland and Whenuapai Airports). However, use of these meteorological data files for undertaking dispersion modelling at other locations could mean that the dispersion modelling was not representative of the location of the discharge.

Steady state Gaussian plume models also have a number of limitations. In particular, they should only be considered appropriate for situations where terrain is not complex or steep, meteorology is spatially uniform and periods of calm or light winds are infrequent. The Auckland region contains complex terrain, and experiences complex land-sea breeze interactions and periods of calm or light wind. More advanced dispersion models, such as CALPUFF, are being used increasingly in an effort to overcome these limitations. CALPUFF has been used for many applications recently.

Complex dispersion models, such as CALPUFF, have significantly greater meteorological data requirements than the steady state models. In particular, they can utilise spatially varying meteorological fields. CALPUFF's meteorological pre-processor, CALMET, is a diagnostic meteorological model which can use data from many monitoring stations. From such information, CALMET produces an hourly three dimensional grid of meteorological variables, which are directly input to CALPUFF. The meteorological datasets produced here as key inputs to CALPUFF have been developed using CALMET.

2.3 Drivers for the development of new meteorological datasets

The ARC previously commissioned the development of a CALMET meteorological dataset that covered most of the Auckland region (ARC, 2002). However, the dataset was developed for a relatively coarse grid resolution and using a version of CALMET no longer compatible with current versions of CALPUFF. Hence an updated CALMET dataset for the region and high resolution CALMET datasets for specific industrial areas and transport corridors have been developed. These datasets are compatible with CALPUFF version 6.

ARC and NZTA recognise that there is still a role for steady state models, such as AUSPLUME, CALINE4 and AUSROADS, in assessments of industrial or land transport projects. The outputs from the high resolution CALMET datasets have been used to generate meteorological data for these steady state models.

3 Overview of dataset development

Different CALMET meteorological datasets have been developed for use with the models CALPUFF, AUSPLUME, CALINE4 and AUSROADS for several areas and discrete locations in the Auckland region. The datasets are developed for CALPUFF, with information extracted from these to produce single station meteorological files for the steady state models AUSPLUME, CALINE4 and AUSROADS. Note that the CALMET datasets can also be used to develop meteorological inputs for other models, such as AERMOD and ADMS-Roads.

Several stages were involved in the development of the CALMET datasets. The methodology is detailed in Appendix A and outlined as follows. It is also schematically illustrated as a flow chart in Figure 3.1.

1. Available meteorological monitoring data for the Auckland region was reviewed, to select suitable monitoring sites and years where data would be suitable for use. In particular, the monitoring site needed to be representative of the general location and not have significant calibration issues or other data anomalies. The final monitoring sites chosen include those located at ARC's ambient air quality sites, supplemented by others in the region under other auspices such as MetService or National Institute of Water & Atmospheric Research (NIWA). A substantial review and quality assurance check of the ARC data has been carried out by WeatherEye Limited (WeatherEye, 2007; 2008). The sites whose data were determined to be of high quality have been incorporated in the dataset development.
2. Two years, 2005 and 2007, were selected following a review of the meteorological and ambient air quality data. This was to provide an indication of inter-annual variability in meteorological conditions. It is recommended that dispersion modelling be undertaken for both 2005 and 2007, with results presented for each year separately.
3. The meteorological data for the two years at the selected sites were formatted for input into CALMET. The modelling described below was thus carried out for each of 2005 and 2007.
4. The prognostic meteorological component of TAPM was run over the region to provide upper air information for input to CALMET, supplementing the surface based measurements from the meteorological sites. TAPM was run to a 1 km grid resolution over Auckland metropolitan urban limits (with 2.5 km resolution over the rest of the region). This is referred to as Stage 1 in Appendix A.
5. Vertical profiles of wind and temperature were extracted from TAPM's results at each meteorological site location. Profiles were also extracted at other locations to ensure a good spatial coverage of vertical profiles throughout the region.
6. CALMET was run for an area covering the Auckland Region at a 1 km grid resolution. This is called Stage 2A in Appendix A. The purpose of this stage is to produce vertically extrapolated profiles over the surface based sites, using Monin-

Obukhov similarity theory (MOST). Profiles from TAPM were offset from the site locations so that the observed wind could be extrapolated according to the theory, up to the mixing height as defined by the TAPM temperature profiles (but without distortion by TAPM's wind profile). This is a convenient way to produce profiles above surface observations, using CALMET's internal algorithms.

7. Profiles for each surface monitoring station and the supplementary locations were extracted from Stage 2A CALMET results. These profiles were blended with those extracted from TAPM at each location (except for those over sea, where the TAPM profile was unaltered). The profile blending is referred to as Stage 2B in Appendix A and was carried out to provide a realistic transition between the surface layer information from CALMET and the upper air information from TAPM.

8. The blended profiles were used as upper air inputs to a second CALMET run over the Auckland Region (Stage 2C). This final regional scale run also provides an hourly three dimensional initial guess field for the high resolution CALMET runs.

9. CALMET was run over 9 sub-areas at 100 m grid resolution, covering specific industrial areas and transport corridors (Stage 3 in Appendix A).

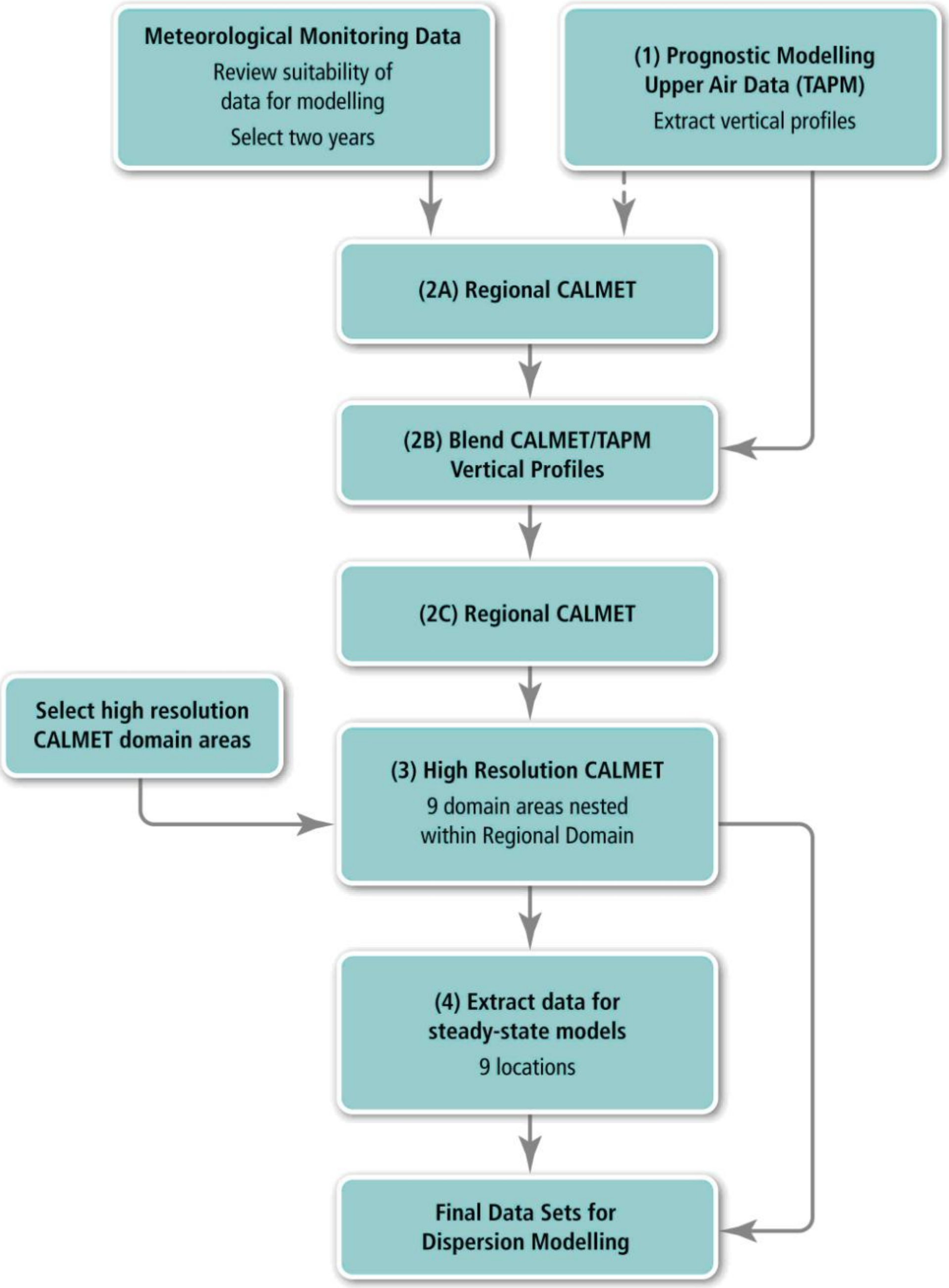
10. Single-point meteorological datasets were extracted from the CALMET results for use with AUSPLUME, CALINE4 and AUSROADS (Stage 4 in Appendix A). A representative location was chosen from each high resolution domain.

11. Scenario tests were undertaken to compare the new AUSPLUME datasets with previous datasets (see Appendix C).

The methods for producing the regional scale initial guess fields for CALMET (to Stage 2) are relatively new. They have been tested as part of a scientific research project (Golder, 2007), and the performance of TAPM and CALMET has been examined to ensure that realistic results have been produced (see Appendix B). More information about the methodology, assumptions and model performance is provided in the appendices.

Figure 3.1

Schematic of meteorological dataset development. The numbers in parentheses are the processing stages referred to in Appendix A.



4 Choice of dispersion model

4.1 Model applicability to physical scenarios

CALPUFF, with three-dimensional meteorology provided by CALMET, is likely to provide more realistic dispersion results in Auckland's complex geographical setting. However, for near-field effects in flat terrain, the use of the steady state plume models with a single-point meteorological file is often justified.

The air dispersion modelling GPG produced by MfE (2004b) provides additional guidance and recommendations on when to use an advanced dispersion model, such as CALPUFF, and when a steady-state Gaussian-plume, such as AUSPLUME, AUSROADS or CALINE4, may be appropriate. The GPG notes the following key situations where a steady state model may be appropriate:

- For near field applications, on spatial scales over which the meteorology may be considered spatially uniform;
- Calm atmospheric conditions are not prevalent;
- Away from a coastal environment and in flat terrain;
- If dry and wet deposition and chemistry do not need to be modelled.

The above bullet points summarise recommendations 3 and 5 of the GPG. The limitations of steady state models are listed on pages 15-16 of the GPG. In the Auckland region for applications beyond these limitations the CALPUFF model should be used with three-dimensional meteorology provided by CALMET.

The bullet points also apply to land transport applications. The air dispersion modelling GPG outlines the features of CALINE4, AUSROADS and ADMS-Roads, which require information on road geometry, traffic density and emission factors. This information is important for dispersion close to the roadside. CALPUFF is not configured to readily accept information on road geometry, traffic density and emission factors; and therefore can not readily be applied to land transport assessments. If a more advanced model is needed for such an assessment, a model such as ADMS-Roads would be more suitable.

Note that a detailed understanding of the interaction of discharged pollutants and background air quality is often required, as both components are spatially and temporally varying. CALPUFF is based on spatially and temporally varying meteorology and can often provide the necessary analysis for this.

Also it should be noted that the provision of meteorological datasets as a basis for dispersion modelling means that the user only needs to configure the dispersion modelling component. The expertise and effort required for this is similar for any of the commonly used dispersion models. For example, there would be no significant difference in the time or effort in configuring CALPUFF compared to AUSPLUME.

4.2 Tiered assessment levels

The GPGs for industrial and land transport assessments (MfE, 2008a; 2008b) describe several levels of assessment, i.e., Tier 1, 2 or 3. The definitions are quoted below:

- Tier 1 – a preliminary assessment to identify whether there are likely to be significant air quality effects;
- Tier 2 – a largely qualitative assessment with screening level modelling only;
- Tier 3 – a largely quantitative assessment with increased complexity in the modelling and reliance on site specific data.

The GPGs state that "a Tier 2 screening dispersion modelling study provides conservative estimates of likely air quality impacts". This may traditionally have meant that the screening dispersion modelling assessment could use a Gaussian-plume model such as AUSPLUME because its results are expected to be conservative. Whilst this may be true if idealised meteorological files (such as "Metsamp") are used, the meteorological files developed here for use with AUSPLUME are derived from CALMET outputs. If the dispersion modelling is of inert tracers in flat terrain with no calms, AUSPLUME and CALPUFF concentrations should be consistent with each other. In other words, the model is not necessarily conservative, but other simplifying assumptions in a Tier 2 assessment may make the results conservative. For example, given a realistic meteorological dataset, conservative results may arise from an assumption of constant maximum emission rates or an assumption of no chemical losses or removal to the surface.

In short, a Tier 2 assessment of effects may include the use of AUSPLUME, CALINE4 or AUSROADS, with some conservative assumptions. If predicted air quality impacts are too high, then a Tier 3 assessment should be carried out. The Tier 3 assessment would then use CALPUFF, AUSROADS or ADMS-Roads to provide a more realistic assessment.

5 Details of the meteorological datasets

5.1 Introduction

Nine high resolution (100 m) three dimensional CALMET meteorological datasets have been developed for areas of significant industrial activity or important transport corridors in the Auckland Region. A further nine datasets have been extracted from the high resolution CALMET datasets at single points for use with AUSPLUME, AUSROADS or CALINE4. The location and extents of each high resolution CALMET domain and the location of each single point dataset are shown in Figure 5.1. All datasets contain hourly meteorological parameters.

An additional CALMET dataset (the regional CALMET dataset) has also been developed as part of the process for generating the nine high resolution CALMET datasets. It covers the whole Auckland Region but at a much lower resolution (1 km) than for the nine high resolution datasets. The regional CALMET dataset is not expected to be used for areas that are covered by the high resolution CALMET datasets.

The remainder of this section details the information specific to each dataset, which is required for the respective dispersion models. Guidance is also provided on the choice of dataset for situations where the dataset domains overlap. Should other air dispersion models, such as AERMOD or ADMS-Roads, be used, their meteorological inputs should be derived from the provided CALMET input or output files.

5.2 CALMET domains

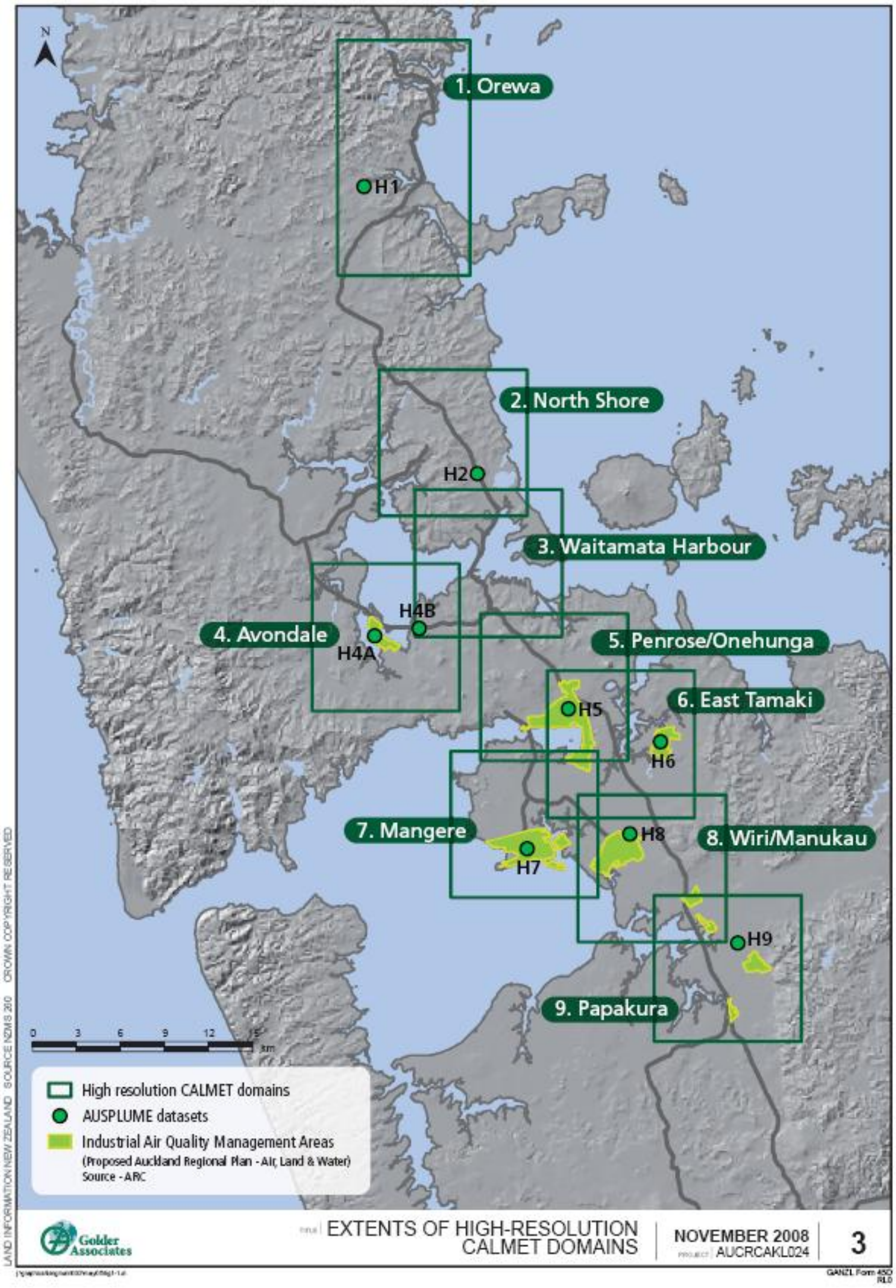
Choice of CALMET domain

The geographic extents (or domains) of several of the high resolution CALMET datasets overlap one another. This overlap is necessary in order to ensure that key industrial areas are reasonably central to at least one of the CALMET domains. However, this can lead to some ambiguity over which dataset to use where a site being assessed falls into two or more domains. For example, an industrial site located in Otahuhu could fall within any of the following domains: Penrose/Onehunga, East Tamaki or Mangere. In situations where this occurs, the dataset that the site is most central to should be used. This helps to ensure that potential impacts of discharges from a site can be assessed over a suitable area centred on the site. For the example of a site located in Otahuhu, this would mean using the East Tamaki dataset.

For locations that are not covered by the nine high resolution CALMET datasets, it may be appropriate to use the low resolution regional CALMET dataset. However, this should only be undertaken following consultation with the ARC. Furthermore, in some instances, such as for large discharge activities located in areas of complex terrain, the low resolution regional CALMET dataset may not appropriate. In such cases, it may be necessary to develop a CALMET dataset suitable for that purpose. This should be undertaken following the methodology of producing the nine high resolution datasets with the regional CALMET dataset as the initial guess field, as described in this document.

Figure 5.1

Location of high resolution CALMET domains and origins of AUSPLUME/AUSROAD datasets. Please check with the ARC or the Auckland Council after 1 November 2010 for the updated Industrial Air Quality Management Areas.



Map projection

CALPUFF requires the map projection of the CALMET dataset used. All of the CALMET domains (both the high resolution and regional domains) use the same map projection of Tangential Transverse Mercator, so that the map projection parameter [PMAP] = TTM. The latitude and longitude, along with a corresponding easting and northing (in New Zealand Transverse Mercator Projection (NZTM) coordinates) for the projection origin, are listed in Table 5.1. NZTM is used because it is the coordinate system for most spatial databases in the region. Although NZTM is not a Tangential Transverse Mercator projection, choice of this option allows any rectangular grid system to be specified, provided that the grid coordinates are linked to the correct latitude and longitude. Also included in Table 5.1 are the relevant CALPUFF parameter names in square brackets.

Table 5.1
Map projection parameters for each high resolution CALMET domain.

Parameter	Value
Latitude [RLAT0]	36.6910 S (decimal degrees)
Longitude [RLON0]	174.7350 E (decimal degrees)
False Easting [FEAST]	1755.000 (NZTM km)
False Northing [FNORTH]	5938.000 (NZTM km)

Geographic extents of CALMET domains

CALPUFF requires the geographic extent and grid configuration of the CALMET dataset. This includes the coordinates of the southwest corner of the domain, along with the number of grid cells and their horizontal spacing. The grid parameters for the nine high resolution CALMET domains and the regional CALMET domain are listed in Table 5.2. Also included in Table 5.2 are the relevant CALPUFF parameter names in square brackets.

The nine high resolution CALMET domains cover areas extending 10 km by 10 km (the exception is the Orewa domain which is 9 km by 16 km), centred on Auckland's IAQMAs. These areas are considered sufficient to capture the likely ranges of air quality impacts from the types of industry present in the Auckland region. Large industries discharging from tall stacks may have a longer range of influence, and therefore, may need to develop a high resolution CALMET dataset with a larger domain size.

CALPUFF also requires the vertical grid structure used in CALMET. For each CALMET domain, 12 vertical layers ([NZ] = 12) were used with the height of each layer face [ZFACE], in metres, as follows:

[ZFACE] = 0, 20, 50, 90, 130, 200, 300, 450, 650, 950, 1400, 2000, 3000.

For 12 layers, there are 13 values of [ZFACE].

Table 5.2

High resolution CALMET domain details.

Domain ID and name	Domain southwest corner (NZTM, km)		Easting grid cells [NX]	Northing grid cells [NY]	Grid spacing (NZTM, km) [DGRIDKM]
	Easting [XORIGKM]	Northing [YORIGKM]			
H1 Orewa	1746.2	5941.9	90	160	0.1
H2 North Shore	1749.1	5925.5	100	100	0.1
H3 Waitamata Harbour	1751.5	5917.4	100	100	0.1
H4 Avondale	1744.5	5912.4	100	100	0.1
H5 Penrose/Onehunga	1755.9	5908.9	100	100	0.1
H6 East Tamaki	1760.5	5905.1	100	100	0.1
H7 Mangere	1753.9	5899.7	100	100	0.1
H8 Wiri/Manukau	1762.6	5896.7	100	100	0.1
H9 Papakura	1767.7	5889.9	100	100	0.1
Reg Regional CALMET domain	1702.0	5870.0	105	135	1.0

Date and time parameters

Each CALMET domain has the same date and time parameters, which are input to CALPUFF. These parameters are listed in Table 5.3 for each year.

Electronic file naming structure

Each CALMET dataset is composed of 12 monthly electronic files for each year. This was done to keep individual files relatively small, as a year's-worth of CALMET output typically occupies 25 GB of disk space.

The files are ordered in directories, firstly according to year (2005 or 2007) and then according to domain. Within each domain directory are located the 12 files that make up the CALMET dataset for that domain and year.

The naming of each CALMET domain is based around the domain ID which is listed in Table 5.2 and shown in Figure 5.1, followed by a number representing the month of the year. For example, CALMET_H1_01.DAT is the CALMET dataset for the Orewa high resolution CALMET domain for January, either in 2005 or 2007 depending on which directory the file is in. An example directory and filename structure is shown in Figure 5.2.

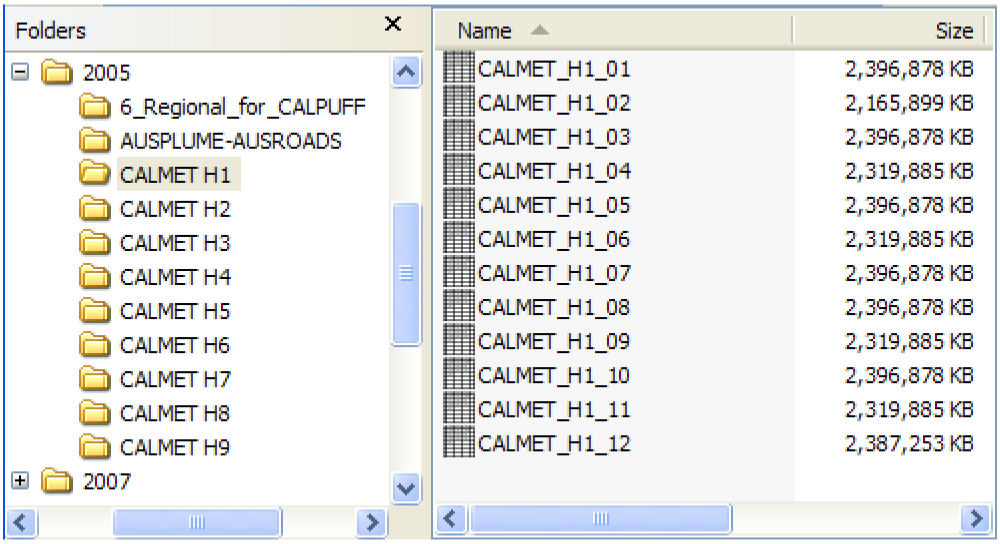
Table 5.3

Date and time parameters for each CALMET domain.

Parameter		Year 2005	Year 2007
Start date	year [IBYR]	2005	2007
	month [IBMO]	1	1
	day [IBDY]	1	1
	hour [IBHR]	0	0
	second [IBSEC]	0	0
End date	year [IEYR]	2005	2007
	month [IEMO]	12	12
	day [IEDY]	31	31
	hour [IEHR]	24	24
	second [IESEC]	0	0
UTC time zone [ABTZ]		UTC+1200	UTC+1200

Figure 5.2

Directory and filename structure for CALMET datasets.



5.3 Datasets for steady state models

Steady state models, such as AUSPLUME, AUSROADS and CALINE4, do not usually require detailed information regarding the meteorological datasets. Instead, the model needs only to know where the meteorological file is located. For reference, the geographic location that each dataset has been generated for is provided in Table 5.4.

For domains H2, H5 and H8, data were extracted from CALMET at the Takapuna, Penrose and Wiri meteorological monitoring site locations, respectively. At these sites, the data are considered to be of good quality (WeatherEye, 2007; 2008), and the surface wind and temperature in the AUSPLUME datasets would match the observations. For the other domains, locations close to the centres of the industrial or transport areas were chosen. The electronic AUSPLUME dataset files follow the same directory and naming structure as for the CALMET dataset described in Section 5.2. Comparison between these datasets and the earlier 1996/1997 datasets can be found in Appendix C.

Table 5.4 lists the meteorological datasets available for Auckland that can be used when running the Gaussian plume models (i.e., AUSPLUME, AUSROADS and CALINE4). Should a Gaussian plume model be used outside the nine major industrial areas and transport corridors, the AUSPLUME dataset may be used from the closest industrial area or transport corridor with similar terrain and land use characteristics. Otherwise, the meteorological input may be derived from an appropriate CALMET dataset (either the regional or generated high resolution CALMET dataset, as discussed in the previous paragraph). The post-processing steps described in this document should be followed in deriving the AUSPLUME dataset.

Table 5.4

Locations of single point datasets for Gaussian-plume models. Names of monitoring site locations, where used, are in parentheses.

Location	Dataset name	NZTM Easting (km)	NZTM Northing (km)
Orewa	H1	1748.114	5947.895
North Shore (Takapuna)	H2	1756.059	5928.077
Avondale	H4A	1748.866	5917.402
Waterview	H4B	1751.822	5917.859
Penrose/Onehunga (Penrose)	H5	1761.751	5914.176
East Tamaki	H6	1768.235	5910.204
Mangere/Airport	H7	1759.169	5902.944
Wiri/Manukau (Wiri)	H8	1766.415	5904.322
Papakura	H9	1773.520	5896.547

6 Recommended "non-default" CALPUFF settings

Most input parameters to CALPUFF have recommended default values. Many of these are switches, relating to a choice of algorithms for the physical processes included in the model. Some of the default parameters are defined by the USEPA for regulatory usage of CALPUFF.

Due to the incorporation of more modern schemes into dispersion models, the most realistic results may be obtained with 'non-default' settings which select the latest schemes. Most of these are discussed in the modelling GPG (MfE, 2004b). Those key parameters which should differ from the default or regulatory settings in CALPUFF are discussed here.

6.1 Choice of building-wake downwash algorithm

The PRIME algorithm ("Plume-Rise Model Enhancements") has been shown to be superior to other building-wake downwash schemes and is now included in AUSPLUME, CALPUFF, TAPM and others. It is recommended that the PRIME option be used [CALPUFF parameter: MBDW=2].

CALPUFF default: [MBDW=1] (ISC method); USEPA default: no default; MfE GPG recommendation: MBDW=2 (PRIME method).

6.2 Calculation of dispersion coefficients

Dispersion coefficients, which determine the horizontal and vertical spread of pollution, can be derived in a variety of ways. In the CALPUFF configuration file, the dispersion coefficient computation method is represented by the parameter [MDISP]. The default method relies on a simpler approach of deriving dispersion coefficients from stability class [MDISP=3]. However, to take full advantage of the CALMET datasets it is recommended that the method of deriving "dispersion coefficients using turbulence calculated from micrometeorology" be used [MDISP=2].

CALPUFF default: [MDISP=3]; USEPA default: [MDISP=2 or 3]. MfE GPG does not make specific recommendations for CALPUFF.

6.3 Dispersion in convective conditions

CALPUFF includes an option for using the probability density function (PDF) method for vertical dispersion in convective conditions. In the CALPUFF configuration file, the PDF method is represented by the parameter [MPDF]. The PDF method is also available in the most recent version of AUSPLUME (version 6), but is not mentioned by MfE (2004b).

The PDF method recognises that the turbulence may not be Gaussian under convective conditions, with vertical dispersion being asymmetrical. This is particularly relevant for dispersion from tall stacks, bringing the plume centreline downwards and leading to higher ground level concentration (GLCs). The PDF method has been verified by scientists at Commonwealth Scientific and Industrial Research Organisation (CSIRO) using standard model validation datasets and is applied in AUSPLUME (version 6) to stacks greater than 100 m in height. It is recommended that the probability density formulation for convective conditions is used in CALPUFF, particularly for tall stacks [MPDF=1]. For all other situations, the sensitivity of the model when using the PDF method should be assessed.

CALPUFF default: [MPDF=0]; USEPA default: [MPDF=0] if [MDISP=3] or [MPDF=1] if [MDISP=2].

7 Summary

A suite of meteorological datasets has been produced for the Auckland region to provide consistent and robust meteorological data for air discharge assessments. They replace previous datasets used in the Auckland region (e.g., 1996 and 1997 AUSPLUME datasets) and those earlier datasets should no longer be used. The datasets have been prepared primarily for CALPUFF and for other commonly used air dispersion models in the region. The hourly three dimensional datasets cover the whole region to a 1 km grid resolution, and nine major industrial areas and transport corridors to a 100 m grid resolution with subsidiary meteorological files for AUSPLUME, AUSROADS or CALINE4. CALPUFF and AUSPLUME are typically used for industrial sources while AUSROADS and CALINE4 for land transport applications. Nine high resolution domains are provided for Orewa, North Shore, Waitamata Harbour, Avondale, Penrose/Onehunga, East Tamaki, Mangere, Wiri/Manukau and Papakura. The datasets are for two years, 2005 and 2007, to allow for inter-annual variability in meteorological conditions.

The Auckland region contains complex terrain, and experiences complex land-sea breeze interactions and periods of calm or light wind. Advanced dispersion models, such as CALPUFF, can be used to overcome these limitations for large industrial air discharges in Auckland. AUSPLUME, AUSROADS and CALINE4 are steady state Gaussian plume models, which require relatively simple meteorological data from single location. They are appropriate for near field applications where terrain is not complex, meteorology is spatially uniform and periods of calm or light winds are infrequent.

The meteorological model CALMET was used to generate the datasets. The prognostic meteorological component of TAPM was used to provide upper air information for input to CALMET, supplementing the surface based measurements from the meteorological sites. TAPM was run to a 1 km grid resolution over Auckland urban areas (with 2.5 km resolution over the rest of the region). Vertical profiles of wind and temperature were extracted from TAPM's results at each meteorological site location. Profiles were also extracted at other locations to ensure a good spatial coverage of vertical profiles throughout the region.

The outputs from TAPM were checked for realistic flows, such as sea breezes and slope flows. They were also compared with observations from selected meteorological sites, and with the 900 mb, 750 mb and 500 mb pressure levels of the Whenuapai soundings. The results show that TAPM performs well over the Auckland region.

The regional CALMET modelling was run twice with the first run to produce vertically extrapolated profiles over the surface based sites using Monin-Obukhov similarity theory (MOST). Profiles from TAPM were offset from the site locations so that the observed wind could be extrapolated up to the mixing height as defined by the TAPM temperature profiles (but without distortion by TAPM's wind profile). This is a convenient way to produce profiles above surface observations, using CALMET's internal algorithms.

Profiles for each surface monitoring station and the supplementary locations were extracted from CALMET results. These profiles were blended with those extracted from TAPM at each location (except for those over sea, where the TAPM profile was unaltered). The profile blending was carried out to provide a realistic transition between the surface layer information from CALMET and the upper air information from TAPM. The blended profiles were used as upper air inputs to the second CALMET run to produce the regional datasets. The datasets for nine industrial areas and transport corridors were produced by the high resolution CALMET runs with the regional run outputs as the initial guess field.

The outputs from CALMET were checked for realistic terrain flows and realistic influences of meteorological observations. The results show a good performance for CALMET. Therefore, the meteorological modelling results are realistic and suitable for use for air dispersion modelling in the Auckland region.

Single-point meteorological datasets were extracted from the CALMET outputs for AUSPLUME, CALINE4 or AUSROADS at a representative location chosen from each high resolution domain. The extracted boundary-layer parameters, such as surface wind, stability class and mixing height, were converted into a format compatible with the Gaussian plume models. Some adjustments were made to ensure consistency between the parameters with reasonable, but conservative, dispersion model results.

The resultant datasets for Gaussian plume models were compared to the previous datasets of 1996 and 1997. There is a different distribution of meteorological parameters between the new and previous datasets. AUSPLUME modelling was carried out for four emission scenarios (a short stack, a taller stack, and low-level area and volume sources) to illustrate the differences of the modelling outputs between the new and previous datasets. Overall, the differences between the new and previous datasets are likely to be due to differences in methodology used for dataset development than to inter-annual changes in the meteorology.

The datasets are supplied as inputs for CALPUFF and Gaussian plume models, so that complex meteorological models need not be run for air discharge assessments. Input files for CALMET are also provided for information. Meteorological datasets have been produced with CALMET version 6.211. They are compatible with CALPUFF versions 6.112 and 6.262, AUSPLUME version 6.0 and AUSROADS version 1.0. Dispersion modelling should be undertaken for both 2005 and 2007, with results presented for each year separately.

It is expected that the new meteorological datasets will be used for all assessments of discharges to air from industrial sources in the Auckland region. NZTA should be consulted for the use of the datasets for assessments of discharges to air from transport projects in the Auckland region. In exceptional circumstances the recommended datasets may not be suitable and an alternative dataset may need to be developed. Should CALPUFF be used outside the nine high resolution CALMET domains, it may be appropriate to use the low resolution regional CALMET dataset. In some instances, such as for large discharge activities located in areas of complex terrain, the regional CALMET dataset may not be appropriate, therefore, it may be necessary to develop a high resolution CALMET dataset suitable for that purpose. This should be undertaken following the methodology of producing the nine high resolution datasets with the regional CALMET dataset as the initial guess field, as described in this document. Should a Gaussian plume model be used outside the nine major industrial areas and transport corridors, the AUSPLUME dataset may be used from the closest industrial area or transport corridor with similar terrain and land use characteristics. Otherwise, the meteorological input may be derived from an appropriate CALMET dataset (either the regional or generated high resolution CALMET dataset). The post-processing steps described in this document should be followed in deriving the AUSPLUME dataset. Should other air dispersion models, such as AERMOD or ADMS-Roads, be used, their meteorological inputs should be derived from the provided CALMET input or output files.

Development of any alternative meteorological datasets for regulatory purposes in the Auckland region in these circumstances should not be undertaken without prior discussions with the ARC for industrial sources or NZTA for transport projects. If an alternative dataset is to be used for a consent application (or notice of requirement for a new or altered designation) a copy of the alternative dataset, together with documentation clearly outlining reasons for the development, methodology, assumptions and the comparison with the recommended datasets, should be provided to the ARC (or the Auckland Council after 1 November 2010) for industrial sources or NZTA for transport projects. The methodology should follow in general the methods as outlined in this guide.

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10 Glossary

ARC	Auckland Regional Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
Golder	Golder Associates (NZ) Limited
MfE	Ministry for the Environment
NIWA	National Institute of Water & Atmospheric Research
NZTA	New Zealand Transport Agency
USEPA	United States Environmental Protection Agency
VicEPA	Environment Protection Authority of Victoria, Australia
WeatherEye	WeatherEye Limited
AEE	Assessment of effects on the environment
CLiDB	National Climate Database
NES	National Environmental Standards (see MfE, 2004a)
RMA	Resource Management Act 1991
GPG	Good-practice guide
PM_{10}	Particulate matter less than 10 microns in diameter
SO_2	Sulphur dioxide
NO_X	Oxides of nitrogen
NO_2	Nitrogen dioxide
TSP	Total suspended particulate
CO	Carbon monoxide
O_3	Ozone
°C	Degrees Celsius
µg/m³	Micrograms per cubic metre
g/s	Grams per second
GLC	Ground level concentration
m/s	Metres per second
GB	Gigabyte
Prognostic model	A computational model which solves mathematical equations to simulate time-dependent atmospheric dynamics. Examples are weather forecasting and climate simulation models. TAPM (see below) is a prognostic model.

Diagnostic model	A computational model which produces instantaneous meteorological fields, based on input observations, prognostic model results, and terrain and land use information. CALMET (see below) is a diagnostic model.
Air dispersion model	A computational model which simulates the dispersion and predicts the downwind concentrations of air pollutants. There is a range of types of model, such as industrial point-source dispersion models (e.g. CALPUFF, AUSPLUME, ISCST3, and AERMOD), line-source models for land transport networks (e.g. CALINE4, AUSROADS, ADMS-Roads) and urban airshed models (see below).
Urban airshed model	A computational model which predicts urban air quality impacts from all source sectors, including industry, motor vehicles, domestic heating and biogenic emissions.
CALMET	A meteorological model, which includes a diagnostic wind field generator containing objective analysis and parameterisation treatments of slope flows, kinematic terrain effects, terrain blocking effects, and a divergence minimisation procedure, and a micrometeorological model for overland and over water boundary layers (definition from Earth Tech, Inc).
CALPUFF	A non-steady-state puff dispersion model which can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal (definition from Earth Tech, Inc).
AUSPLUME	Steady-state Gaussian-plume model for industrial point source applications (VicEPA).
AUSROADS	Steady-state Gaussian-plume model for land transport applications (VicEPA).
CALINE4	Steady-state Gaussian-plume model for land transport applications (California Air Resources Board - CARB).
TAPM	The Air Pollution Model (CSIRO).
ISCST3	Steady-state Gaussian-plume model for industrial point source applications.

Boundary layer	The part of the atmosphere directly influenced by the earth's surface, which responds to surface forcing over a timescale of one hour or less (Stull, 1988).
Mixing height (or mixing depth)	The thickness of the layer measured from the surface upwards, through which pollutants are presumed to mix due to convection caused by daytime heating of the surface (Oke, 1987).
Surface layer	The lowest part of the boundary layer. A layer of air of the order of tens of meters thick adjacent to the ground where mechanical (shear) generation of turbulence exceeds buoyant generation or consumption.
Monin-Obukhov Similarity Theory (MOST)	"A relationship describing the vertical behaviour of nondimensionalised mean flow and turbulence properties within the atmospheric surface layer (the lowest 10% or so of the atmospheric boundary layer) as a function of the Monin–Obukhov key parameters." (quoted from http://amsglossary.allenpress.com/glossary). This theory is used in CALMET to extrapolate vertical profiles of meteorological parameters through the atmospheric boundary layer.
Initial guess	At each hour, the first calculation stage in CALMET in which all input data are interpolated to produce three-dimensional meteorological fields. This stage is

	followed by incorporation of terrain effects (Step 1) and the objective analysis of weather and climate data to produce a final three-dimensional field (Step 2).
Upper air	The air above the surface layer (including the air above the boundary layer).
NZTM	New Zealand Transverse Mercator Projection.
IAQMA	Industrial Air Quality Management Area from the Proposed Auckland Regional Plan: Air, Land and Water.

Appendix A: Detailed modelling methodology

A.1 Introduction to the methodology

The production of meteorological datasets for the Auckland region is centred on the use of CALMET. Meteorological information sources for CALMET are observations, prognostic model outputs, or a combination of both, and CALMET includes a number of options for different ways of incorporating this information.

CALMET is suited to the incorporation of outputs from the prognostic model MM5, and can use these in a straightforward way. MM5 supplies an 'initial guess' of the three dimensional meteorology at each hour in the form of a three dimensional grid of meteorological parameters, which is interpolated onto the (finer) CALMET grid. CALMET is also able to incorporate the horizontal wind components from other models, which may require re-formatting as an interim step.

In the current work, TAPM has been used to provide the prognostic fields as part of the CALMET initial guess. The meteorological module of TAPM is simplified relative to MM5, being hydrostatic and having less sophisticated microphysical schemes. TAPM has been developed specifically for air quality applications and has been used here for the following reasons:

1) Meteorological processes which are filtered out by or not included in TAPM's numerical formulation, such as complex microphysics, gravity-wave propagation, deep convection, were not considered important by its developers for air-pollution dispersion applications, or their complexity not considered necessary.

2) The complex processes are computing-intensive. Run times are reduced if they are not simulated, allowing long-term simulations to be carried out at high resolution on a PC. A year-long simulation takes a few days.

3) Conversely, MM5 would require a high-performance computing facility to produce a historical dataset for a chosen year.

4) TAPM is more practical to use. Its performance has been validated in the literature many times, and has also been validated for this work (see Appendix B).

At the time of production of the datasets for Auckland, there was no TAPM-CALMET interface for the latest versions of each model, so an alternative method for incorporating TAPM information into CALMET has been used. This involves extracting hourly vertical profiles from TAPM and concurrently running CALMET to create hourly profiles by extrapolating upwards from surface observations. The two profile types have been blended together at each surface site, with the resulting profiles input to a second run of CALMET as if they were observations. The surface site locations are supplemented over the sea and in data-sparse regions over the land by sites where profiles and surface information are both taken from TAPM. The procedure is outlined more fully below (Sections A.5.1 to A.5.2.4).

CALMET has been run using information from a collection of spatially discrete sites: weather stations plus several extra locations. There is clearly less information than would be contained in an hourly three dimensional grid of points or provided by MM5, and the results must be inspected to ensure that CALMET produces meteorological fields with a realistic three dimensional structure. This is also investigated in Appendix B. The resulting CALMET fields have the following features:

1) The near surface meteorology is determined by surface observations at ARC and National Climate Database (CLiDB) sites, or by TAPM in data-sparse areas. CALMET output matches observations at the sites and changes in meteorological fields between sites are smooth.

2) Physically realistic upper air meteorology is specified by hourly profiles from TAPM (and validated by comparison with Whenuapai profiles in Appendix B at several levels).

3) There is a smooth transition vertically between the surface and upper air fields.

4) Surface observations are extrapolated through the surface layer, merging with TAPM profiles through the rest of the atmospheric boundary layer.

Grid-cell-averaged meteorological parameters output by a prognostic model do not need to match measurements made at a location representative of a smaller area hour by hour. The prognostic model may perform well in a statistical sense over a long period, but the incorporation of its results, along with measurements from a weather station into CALMET are done hourly. There may be an inconsistency between prognostic model output and observations, which can manifest itself in CALMET results as a sharp gradient in conditions. For example, this may be seen as a small "bulls-eye" of a particular wind speed and direction, surrounded by an area of quite different winds, with an abrupt transition between them. CALMET extrapolates surface observations to the boundary layer height, so if a nearby profile, whether observed or extracted from a prognostic model, is different, then an abrupt change in the horizontal may be seen at all levels. This is also possible when a profile extrapolated from surface observations is superposed on a gridded three dimensional initial guess field from a prognostic model. In addition, CALMET does not need to allow vertical extrapolation of surface observations, and does not need to use profile information in the lowest model level, but that can lead to an abrupt change in the vertical profile, between the first and second model levels.

The method described above prevents the occurrence of unrealistically strong gradients in meteorological parameters. It also produces a CALMET solution above the surface layer consistent with TAPM, rather than a similarity theory extrapolation (as the theory is strictly only valid in the surface layer).

CALMET results are supplied as binary output files so that they can be used directly for CALPUFF runs. It has the advantages that the time required to configure and run CALMET is saved. The input files are also supplied for the user to run CALMET if needed.

In the project, CALMET has been used in several ways. These are:

1) As a tool to produce theoretical profiles above surface sites.

2) To produce three dimensional fields at the regional scale as the initial guess fields for high resolution nested runs. This uses pre–blended profiles and no extrapolation is carried in the CALMET run.

3) To produce high resolution datasets over industrial areas and transport corridors.

4) Single point datasets have been extracted from the final CALMET results for use with AUSPLUME, CALINE4 or AUSROADS.

The following sections detail the methodology.

A.2 Model requirements

CALMET requires topographical and meteorological data as inputs. To produce realistic results, good quality meteorological data from sites representative of their surroundings are crucial. Also, inter-annual variability in the meteorology contributes to variability in air quality, and care must be taken in the choice of years to be modelled. We have modelled two full years, determined by the likelihood of worst case air quality for different source types.

The process of developing the datasets contains several stages, which are discussed below. These are:

- The selection of meteorological data from local meteorological stations, according to their representative of the surroundings and suitability for incorporation into CALMET (discussed in Section A.3).
- The selection of two years to model, to provide an indication of year to year variability (discussed in Section A.4).
- The multi-stage modelling procedure, using TAPM for the large scale meteorology, and CALMET to cover both the Auckland region and the individual areas of interest for dispersion modelling from industrial sources and transport projects (discussed in Section A.5).

A.3 Meteorological site selection

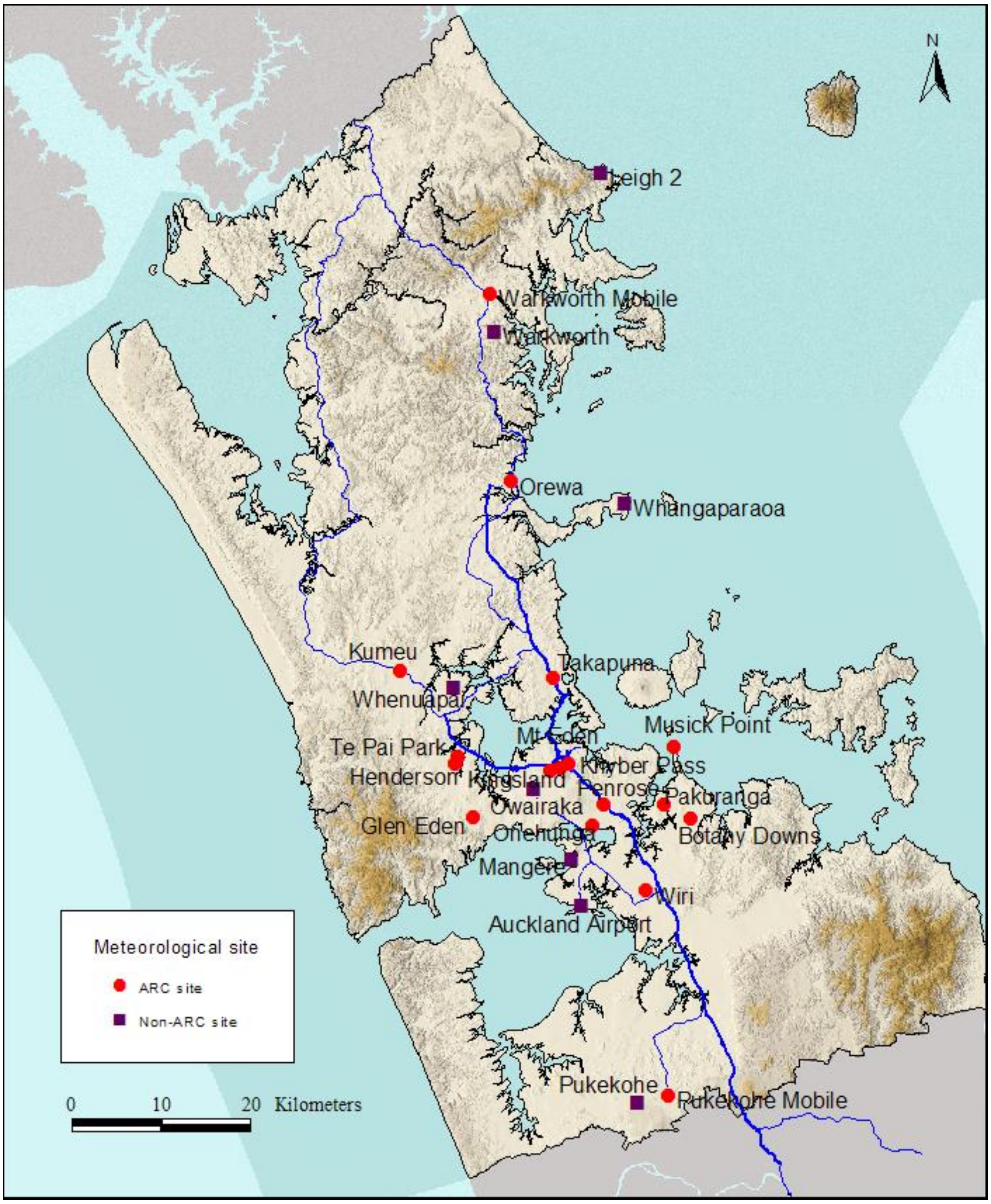
The Auckland region has a good coverage of meteorological stations. Many are operated for the ARC as part of its air quality monitoring network. Some are operated by MetService as part of its weather observing network, and some on behalf of other organisations such as Crown Research Institutes (see Figure A.1).

CALMET requires surface-based meteorological data as input. It is important, therefore, to review the quality and suitability of the available data. This has been carried out by WeatherEye Limited (WeatherEye, 2007; 2008) for the meteorological monitoring at ARC-owned air quality sites, and some MetService sites.

The WeatherEye Limited reviews examined data quality, for example, instrument calibration, inter-site variability, unusual or unrealistic data, and siting issues, for example, sheltering from prevailing winds, effect of turbulence around nearby obstacles. For each meteorological parameter (wind speed, wind direction, temperature, humidity and solar radiation), the sites were characterised as being of good, moderate or poor quality, as a result of the assessment.

For CALMET, the most important parameters are wind speed and direction, and the proposed choice of usable sites is based on the quality of those parameters.

Figure A.1
Meteorological sites in the Auckland region, including ARC-owned and other sites.



A.3.1 Selected meteorological sites for CALMET modelling

Only the sites that were categorised as good or moderate for wind data by the WeatherEye review are used in CALMET modelling. These are Takapuna, Khyber Pass, Te Pai Park, Onehunga, Penrose, Wiri, Pukekohe and Musick Point. These sites may still have some of the lesser problems discussed in the WeatherEye reports, and we have carried out some similar basic checks to reject unsuitable data from them. We have not used data from the following ARC or MetService sites:

- Mt Eden and Kingsland – these have problems with surrounding obstacles to air flow, and are close to Khyber Pass which was categorised as a good site.
- Henderson - Te Pai Park is a better quality site for that vicinity.
- Glen Eden, Pakuranga, Botany Downs – these are sheltered from the prevailing wind and subject to turbulence around nearby obstacles (which will give erroneous wind directions). There are also calibration problems.
- Whangaparaoa – this is exposed at the tip of the peninsula to marine meteorology and not appropriate to pollution dispersion over land. CALMET model runs would produce sharp gradients around the site due to its higher wind speed, which would not be consistent with the geography and local wind flows around an elongated peninsula. The site also had long periods of zero wind speed, some of these possibly due to wind sensors being affected by sea spray.
- Auckland Airport – use of wind data from airport sites for dispersion modelling needs special care (this was discussed at the CASANZ modelling workshop in Brisbane, September 2007). Monitoring equipment is designed to be robust at higher wind speeds, for aviation purposes and forecasting of extreme winds. It can often have a high stall speed, and therefore not produce good observations at the low wind speeds critical for air pollution events. However, cloud, pressure and rainfall data from this site have been input to the CALMET modelling.

A.3.2 Additional meteorological sites for CALMET modelling

There are some areas in the Auckland region that are not covered by the ARC meteorological data, mainly to the north of the urban areas. CliDB includes the following sites, whose data have been included in the CALMET modelling (the observing authority is in parentheses):

- Mangere (NIWA) – this is a good alternative to the Airport in the vicinity south of Auckland city and west of Manukau city, although there are periods of missing data.
- Warkworth (NIWA).
- Leigh 2 (observing authority not recorded on CliDB).
- Owairaka (observing authority not recorded on CliDB).

Whilst data from these sites have been in the CALMET modelling, they have not been subjected to the same degree of review and testing as that carried out by WeatherEye Limited for the ARC data.

A.3.3 Summary of meteorological sites chosen for CALMET modelling

In summary, the surface based sites incorporated into the CALMET modelling, along with the observed parameters used, are shown in Table A.1. These sites provide a good coverage over the Auckland region with reliable data.

Table A.1
Meteorological sites and data used as input to CALMET (shown by x).

Site	Wind	Temperature	Humidity	Rainfall	Cloud	Pressure
Takapuna	x	x	x			
Khyber Pass	x	x	x			
Te Pai Park	x	x	x			
Onehunga	x	x	x			
Penrose	x	x	x			
Wiri	x	x	x			
Pukekohe	x	x	x	x		
Musick Point	x	x	x			
Mangere	x	x	x	x		
Warkworth	x	x	x	x		
Leigh 2	x	x	x	x		
Auckland Airport				x	x	x
Owairaka				x		

A.3.4 Scalar and vector averaging of wind speed

There are two ways of calculating the hourly average wind speed. The scalar average is simply the average of the wind speed measurements within each hour. The vector average wind is calculated from the average of its components (eastwards and northwards) within each hour. Some wind speed data may report at hourly intervals the average over the final ten minutes of each hour.

The vector average wind is the true average over the hour, as it measures the resulting air mass movement in that time, accounting for re-circulation in light and variable wind. The scalar average wind speed is always equal to or higher than the speed of the vector average wind, and the difference between the two is most marked at lower wind speeds, where the direction is more changeable.

The scalar average wind speed is the appropriate quantity for modelling pollution dispersion. A cloud or plume of pollutants diffuses and dilutes even if the vector average wind is zero. The scalar average wind speed is recommended for use in

Gaussian-plume models, and in CALMET. This is because CALMET's turbulent diffusion depends ultimately on the wind speed. If the wind speed is zero, pollutants will not drift away from their source. They will not disperse in situ either, and the use of vector average quantities will lead to unrealistically high concentrations.

Of the ARC meteorological sites, those run by Watercare (Musick Point, Penrose, and Takapuna) report vector average wind speed, and those run by NIWA report scalar average wind speed. Hourly scalar averages of wind speed at Watercare sites have been derived from the 10 minute data and used as CALMET input. The wind direction at all the sites is the vector-averaged result. In summary, the scalar wind speed averaged over an hour is used for CALMET input in this report.

A.4 Selection of years for meteorological modelling

It is considered that dispersion modelling for air quality assessments should be carried out at least for two years in order to obtain an indication of year-to-year variability in pollution concentrations. In this section, methods for determining suitable years on the basis of variations in peak impacts from industry, transport and baseline urban air quality levels (including contributions from domestic heating) are discussed.

A.4.1 Air quality impacts

There are several aspects to consider in the choice of suitable years to model. These involve a prediction of likely air quality impacts using meteorological data, or existing baseline ambient air quality data.

The meteorological datasets are intended for air quality impact assessments for industrial and transport sources. These source types can have differing impacts under the same meteorological conditions. This is primarily due to different release heights, e.g., tall stacks versus vehicle tailpipes. For high ground-level concentrations to occur from tall industrial stacks there needs to be diffusion downwards; for high ground-level concentrations to occur from vehicle tailpipes, diffusion upwards should be restricted. The diffusion of pollutants depends on the turbulent energy of the atmosphere, which relates to its stability.

In addition, the cumulative effects of new sources include baseline or background levels of air pollutants, due to domestic heating, the "rest" of the transport network, or natural sources such as wind-blown dust or sea spray. Accordingly, the choice of years needs to consider variations in likely baseline levels.

Using the meteorology as an indicator of likely potential air quality impacts, the following have been examined:

1) Meteorological conditions giving rise to a higher frequency of peak impacts from tall stacks, and

2) Meteorological conditions giving rise to a higher frequency of peak impacts from low level sources, such as new transport projects, and background sources such as existing motor vehicles and domestic heating.

The relevant meteorological conditions differ between source-types, and hence a choice of years based on these meteorological conditions provides an indication in subsequent dispersion modelling of year-to-year variability.

A.4.2 Criteria for choice of years

Specific criteria for choosing suitable years have been examined. These are:

1) Higher frequency of meteorological conditions causing higher modelled concentrations,

2) Higher baseline ambient air pollution levels, and

3) A larger number of usable meteorological sites (so that more recent years are more suitable).

Of these, only the first two are related to finding the worst years for air quality impacts. The third is related to providing good quality datasets, based on good quality input data. The criteria are discussed in the following sections.

A.4.3 Meteorological conditions

Air quality assessments using dispersion models are typically carried out using a fixed source discharge rate (the rate for which the resource consent is being applied). Hence variations in air quality impacts are determined by variations in meteorological conditions.

Results from dispersion modelling exercises are predictable to some extent, in terms of their qualitative dependence on the meteorology. Examples are mentioned above – peak impacts during stable conditions for low-level sources and moderately unstable conditions for tall stacks.

As the meteorological inputs determine the modelled air quality impacts (under constant emission rates), criteria regarding meteorological conditions are directly relevant to the selection of modelled years. Such criteria should be considered more important than the observed air quality at monitoring sites, as this is not wholly dependent on the meteorology. It is also dependent on variability in emissions and atmospheric chemistry. This point will be returned to in Section A.4.4.

A.4.3.1 Peak concentrations from tall stack discharges

The worst air quality impacts from industrial plants can typically occur in unstable conditions at moderate wind speeds. High modelled ground level concentrations from tall stacks occur often during stability conditions of Pasquill-Gifford class B or C (weak instability). The model's diffusion parameters and the characteristics of the dispersed plume can depend explicitly on the stability class.

To determine years of likely peak impacts from tall discharge sources, the meteorological data for times when the wind speed is between 3 m/s and 5 m/s, and the incoming solar radiation is greater than 25 W/m2 (to denote daytime) have been examined. A "worst-case" year is one with a high frequency of such conditions.

A.4.3.2 Peak concentrations from low-level sources

Peak concentrations from low-level sources typically occur under calm and stable conditions, when discharged air pollutants are trapped in a shallow layer. Also, impacts from motor vehicles can be high under low wind speeds, irrespective of the stability of the atmosphere. This is because of the close proximity of people to the roadside (either as pedestrians or whose homes are next to the road), who experience air pollutants discharged from vehicle tailpipes before the pollutants have dispersed further.

Figures A.2 and A.3 show scatter-plots of 24-hour PM10 against wind run (the scalar-average wind speed) at Henderson for 2005 to 2007. Figure A.2 shows the winter months (June, July and August) and Figure A.3 the rest of the year. A signature of elevated PM10 at low wind speeds can be seen in winter (Figure A.2). PM10 levels reach 40 μg/m3 when the average wind speed is less than 1 m/s. However, there are many instances of PM10 around 30 μg/m3 occurring at average wind speeds up to 3 m/s.

During the rest of the year, levels of PM10 are similar, but without the increasing trend at lower wind speeds. As there is a very slight downward trend in winter PM10 with increasing wind speed, it is apparent that peak impacts from low-level sources typically occur when the hourly wind speed is less than 3 m/s, and a worst-case year would be one with a high frequency of these conditions. Daytime and night-time (incoming radiation above or below 25 W/m2) have been considered separately.

Figure A.2

Wintertime (June, July and August) PM_{10} at Henderson plotted against daily wind run (proportional to the scalar-average wind speed).

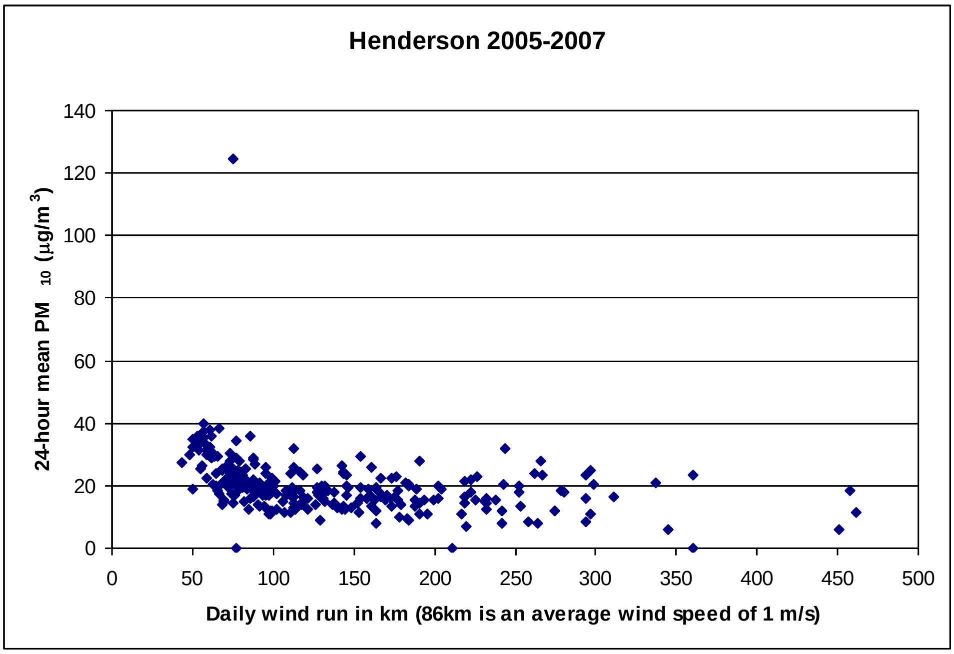
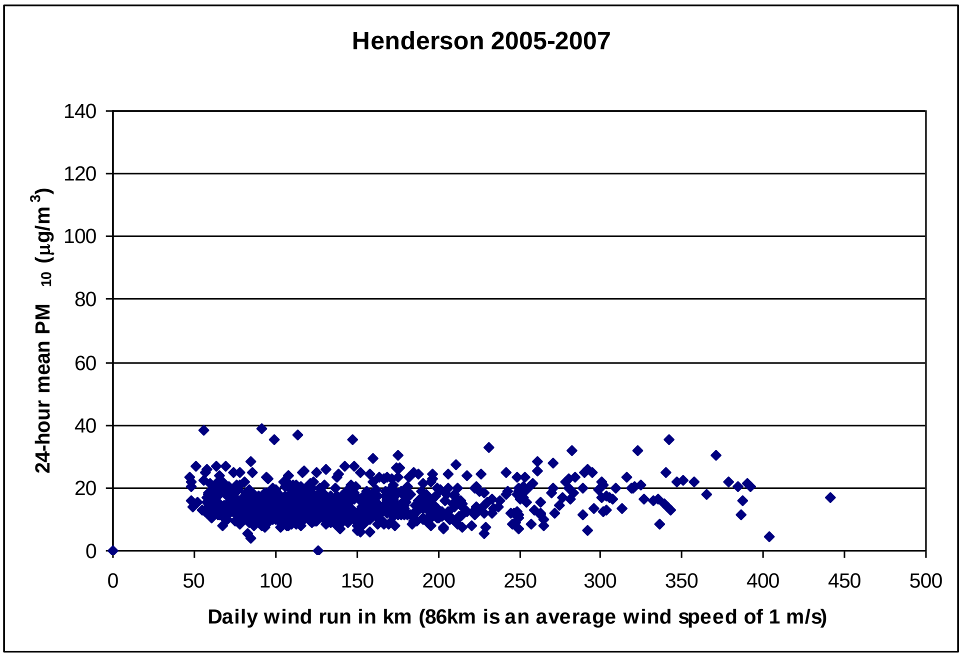


Figure A.3

PM_{10} at Henderson plotted against daily wind run (proportional to the scalar-average wind speed) for January - May and September - December.



A.4.3.3 Examination of meteorological data

The hourly wind speed at Takapuna, Wiri and Onehunga during daytime and night-time have been considered. These sites are categorized as "good" for wind data in the WeatherEye reviews (WeatherEye 2007; 2008), and are in widely-separated locations across the region. Figure A.4 shows the percentage of daytime hours for the wind speed in the ranges of 0 - 3 m/s and 3 - 5 m/s at the Wiri meteorological site. The highest proportion in the 3 - 5 m/s range occurred in 2001, followed by 2005, 2007, 1999 and 2003. For the range of 0 - 3 m/s the years were 2003, followed by 2001, 2005, 1999 and 2007. Examination of the data at several sites shows that higher frequencies of wind speeds in the chosen ranges do not occur in the same year for all sites.

It is a challenge to choose two years which include higher than average wind speeds in both ranges at each site. For the three sites and the three sets of critical conditions (daytime wind speed 3 - 5 m/s, daytime wind speed 0 - 3 m/s and night-time wind speed 0 - 3 m/s), Table A.2 shows the years ordered according to frequency of those conditions, starting with the most frequent. The years 2005, 2001, 2006 and 2007 are in bold in the table. These years appear in the first three rows for each site most frequently. Variability between sites can be seen here. For instance, for tall-stack discharges, with a critical wind speed range of 3 - 5 m/s, 2005 is appropriate for Onehunga and 2001 for Takapuna. At Wiri, that range occurs more frequently in both 2001 and 2005.

Figure A.4

Percentage of daytime hours for the wind speed in the ranges of 0 – 3 m/s and 3 – 5 m/s at Wiri.

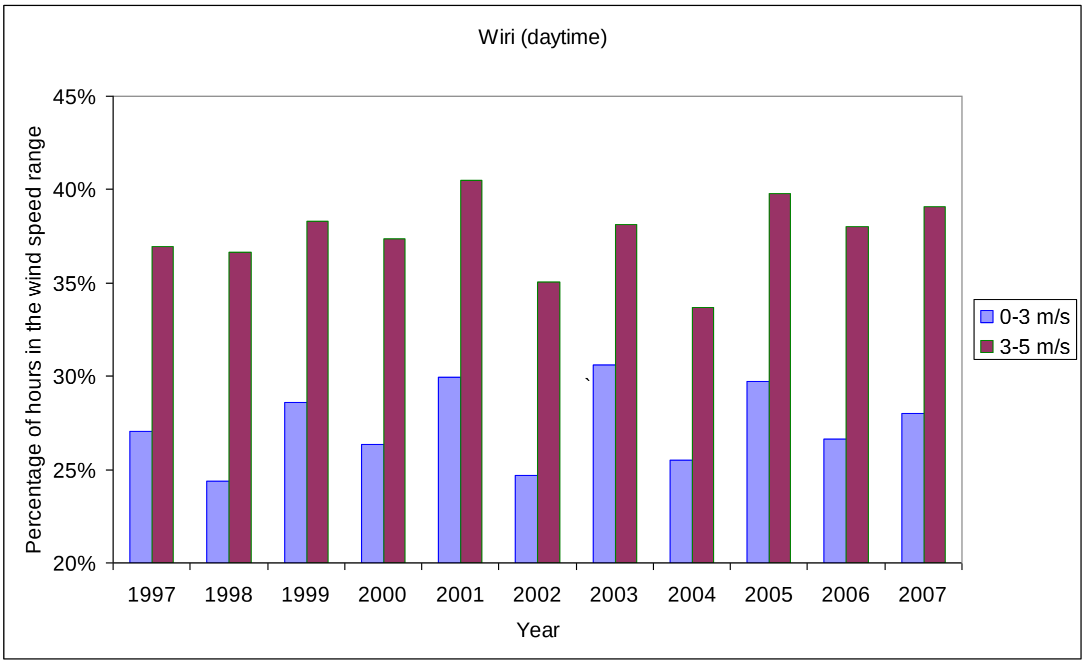


Table A.2

Year of data ranked according to frequency of meteorological conditions (the highest at the top, and the lowest at the bottom).

Onehunga			Takapuna			Wiri		
Daytime		Night-time	Daytime		Night-time	Daytime		Night-time
3-5 m/s	0-3 m/s	0-3 m/s	3-5 m/s	0-3 m/s	0-3 m/s	3-5 m/s	0-3 m/s	0-3 m/s
2005	**2007**	**2005**	**2001**	**2005**	**2005**	**2001**	2003	**2005**
2006	**2005**	**2007**	1999	**2007**	**2006**	**2005**	**2001**	2003
1999	**2001**	**2006**	2003	**2006**	2004	**2007**	**2005**	**2001**
2000	**2006**	**2001**	2000	2004	2003	1999	1999	1999
2007	2003	2003	1995	2003	**2007**	2003	**2007**	**2007**
2001	2004	1999	1997	1999	1999	**2006**	1997	**2006**
2003	2002	2004	1996	1998	**2001**	2000	**2006**	1997
2002	1997	1997	**2006**	**2001**	2000	1997	2000	2000
1995	1999	2002	2002	2000	1997	1998	2004	2004
2004	2000	2000	1998	2002	1998	2002	2002	2002
1996	1995	1995	**2007**	1996	2002	2004	1998	1998
1998	1996	1996	2004	1997	1996			
1997	1998	1998	**2005**	1995	1995			

A.4.4 Observed ambient air quality

Observed ambient air quality may be heavily influenced by the sources close to the monitoring sites. For instance, Khyber Pass and Queen Street may be dominated by motor vehicle pollution, Penrose by industrial pollution, and Henderson and Botany downs by home heating. However, recent source apportionment analysis of PM10 data has shown the contributions of different source types. For instance, there is a significant signature of domestic biomass burning, even at the Queen Street site, there is a negligible contribution from industry, even at Penrose, and there is a significant contribution from sea salt at many sites (GNS, 2007).

Air quality data over the Auckland region have been examined for consistency with findings from the meteorological data. However, variability in levels of air pollutants is not explainable solely by the meteorological conditions. As concentrations depend on emissions and meteorology, there is an apparent randomness in them arising through variability in emissions. This could be especially true at the high-end of the concentration distribution, where exceedences of the National Environmental Standard (NES) for PM10 may arise through emissions not accounted for in an inventory of a "typical day" emissions.

PM10 concentrations have been considered at Henderson, Takapuna, Queen Street, Khyber Pass, Mount Eden and Penrose. Peak concentrations (higher than 33 μg/m3) are used to indicate air quality impacts. As monitoring has been historically carried out 1-in-3 or 1-in-6 days, rather than daily, and as monitoring methods have been changed over the years, the number of peak concentrations cannot be compared directly. However, it can be presented as a fraction of the number of days' observations taken during each year for comparison. The results for concentrations above 33 μg/m3 and 50 μg/m3 are presented in Tables A.3 and A.4, respectively.

From Table A.3, it appears that the worst years for PM10 are 2000, then 2004. However, at Henderson the worst PM10 impacts occurred in 2001 and 2005 (according to the Partisol data). From Table A.4, it appears that the worst year is 2000. These results, compared to the worst-case meteorological conditions identified in Table A.2, suggest that peak PM10 levels are not totally defined by the meteorology.

NOx data from several sites in Auckland have also been examined. In the case of NOx there are no years with significantly higher levels than the neighbouring years, but there has been a general downward trend in NOx since around 2004.

It is unsurprising that a choice of the worst-case year for industrial impacts based on the meteorology is not consistent with years implied by the ambient air quality record, given that there is a negligible signature of industry in that record. However, it is worth reiterating that modelling assessments of industrial impacts depend on the meteorology and that the choice of year should be based on wind data, not ambient PM10 data.

Also, it is not surprising that the years with highest PM10 measurements are not those of low wind speed. A significant contribution from natural sources (such as sea salt and wind-blown dust) may arise during conditions of higher wind speed.

Table A.3

Per cent of days with observed 24-hour PM_{10} above 33 µg/m³. Years without observations are shaded.

Year	Penrose*		Khyber Pass	Henderson		Takapuna		Queen St	Mt Eden	
	HiVol / Partisol	BAM	Partisol	BAM	Partisol	BAM	Partisol	BAM	Partisol	BAM
2000	11		19	3		0		12	8	
2001	3		7	12		4		9	3	
2002	4		4	0		4		7	1	0
2003	4	5	3	3	4	4		8	0	1
2004		4	5	1	2	9	7	13	1	1
2005		1	2	6	0	2	1	1		0
2006		1	2	1	3	4	4	2		0
2007		2	3	2	1	4	3	5		

* HiVol data are at the Penrose (Great South Road, Clinic Roof) site for 2000 and 2001, Partisol at the Penrose III(B) (ACI) site for 2002 and 2003. BAM (beta attenuation monitor) data are at the Penrose II(B) (Gavin St) site.

Table A.4

Per cent of days with observed 24-hour PM_{10} above 50 µg/m³. Years without observations are shaded.

Year	Penrose*		Khyber Pass	Henderson		Takapuna		Queen St	Mt Eden	
	HiVol / Partisol	BAM	Partisol	BAM	Partisol	BAM	Partisol	BAM	Partisol	BAM
2000	2		4	0		0		4	0	
2001	2		1	0		2		1	1	
2002	0		3	0		0		0	0	0
2003	2	0	0	0	0	0		0	0	0
2004		0	0	0	0	0	0	1	0	0
2005		0	1	0	0	1	0	0		0
2006		0	0	0	0	0	0	0		0
2007		0	0	0	0	0	0	1		

* HiVol data are at the Penrose (Great South Road, Clinic Roof) site for 2000 and 2001, Partisol at the Penrose III(B) (ACI) site for 2002 and 2003. BAM data are at the Penrose II(B) (Gavin St) site.

A.4.5 Summary – final choice of modelled years

From the examination of local meteorological data, candidate years to model are 2001, 2005, 2006 and 2007. However, there were fewer meteorological sites in operation in 2001, and better modelled datasets should result from a larger amount of good-quality input data. The year 2005 is a good candidate from a meteorological point of view, along with either 2006 or 2007. However, the year 2007 features more prominently than 2006 in Table A.2.

To compare between the candidate years and the long term average, the annual-mean wind data from Auckland airport have been considered. The 30-year average wind speed at Auckland airport is 4.9 m/s. The annual-mean wind speed is 4.4 m/s for 2001, 4.5 m/s for 2005, 4.8 m/s for 2006 and 4.7 m/s for 2007. They are very close to the long term average. Therefore, these years are considered representative.

On consideration of several aspects, including meteorological trends, and the availability of meteorological data, the two years chosen are 2005 and 2007. These years have the potential for high air quality impacts from industrial sources and transport projects. Carrying out modelling assessments using both years is unlikely to result in understating air quality impacts. An indication of inter-annual variability can be gained from a two-year dispersion modelling exercise.

A.5 Modelling methodology

Meteorological datasets are developed to support the CALPUFF, AUSPLUME, CALINE4 or AUSROADS models. Focusing on key industrial and roading project areas, the CALPUFF dispersion model needs to be based on high-resolution meteorological fields. This is due to the complex coastal topography of the Auckland region, which produces spatially-varying weather patterns that need to be captured by a three-dimensional meteorological model. Therefore, the domains of interest have been modelled at high resolution using CALMET.

For short range applications, where the meteorology may be considered horizontally homogeneous, time series of meteorology at single locations for use with Gaussian-plume models AUSPLUME, CALINE4 and AUSROADS have been extracted from the CALMET outputs.

The complexity of the topography and coastline of the Auckland region means there may be wind flow patterns in the high-resolution domains which are driven by terrain and land-use changes not included in those domains. To overcome this, the high-resolution CALMET domains (grid-cell size 100 m) have been nested within a coarser domain which covers the whole Auckland region (105 km x 135 km, W-E x S-N, at grid-cell size 1 km). Using this feature in CALMET means that the results from the coarse-resolution model run are used as the initial guess of the fields on the fine grids, which are adjusted according to the fine-scale topography.

Using the nesting capabilities of CALMET has lead to a collection of datasets with consistent meteorology between scales. Extracting the meteorology from CALMET for the Gaussian-plume models also lends consistency between the models. Having a region-wide basic meteorological dataset allows further fine-grid datasets to be produced as needed in the region.

CALMET requires hourly surface-based meteorological data and 12-hourly vertical profiles from at least one location. The model interpolates between these input data. Although surface sites are relatively plentiful in the Auckland region, there are some areas away from the central urban area where surface data are sparse or non-existent. Furthermore, data from some of the sites are not suitable for use as inputs to a meteorological model.

Vertical profiles are available twice daily from Whenuapai. These are not sufficient to capture the time-dependent three-dimensional structure of the atmosphere above Auckland, and it is necessary to supplement the meteorological data with outputs from a prognostic meteorological model.

CALMET is able to base its initial-guess fields on outputs from the MM5 model. In this work, we have used TAPM to provide supplementary meteorological information to CALMET. The method for incorporating results from TAPM into CALMET is described in detail below.

A logical sequence of modelling is presented in this section, from the preparation of data, the running of TAPM, to the running of CALMET at different resolutions, and the extraction of data for use with Gaussian-plume models.

A.5.1 Stage 1 – prognostic modelling

Prognostic models such as MM5 and TAPM solve the equations of atmospheric dynamics to produce physically realistic three-dimensional meteorological fields, such as wind, temperature, humidity, surface fluxes and boundary-layer structure. They are the models used in weather forecasting and climate research, and as a basis for dispersion modelling. They do not require data from local climate stations, as local flows arise through the dynamical forcing simulated by the computational model. However, they do require larger scale fields (up to global scale) for their initialization and ongoing boundary updates.

CALMET requires data inputs from local surface-based weather stations and vertical profiles. If these are sparsely distributed (or even absent) the surface data has been supplemented by prognostic model outputs. As pointed out above, TAPM has been used in the development of the datasets for Auckland to provide upper-air profiles and some surface-based outputs to initialize CALMET. TAPM is a PC based model, in fairly common use among consultants in New Zealand, and developed specifically for air quality applications. Provided TAPM performs well, it is a viable alternative to MM5, and we have used standard statistical performance measures to show that this is the case. The performance evaluation of TAPM is included in Appendix B. Note that TAPM has already been tested on the Auckland region and has been shown to perform well (Gimson, 2005).

Although TAPM has been run for the Auckland region, there is still a need to run CALMET to provide fine resolution meteorological fields. The reasons for this are as follows:

- Currently, the dispersion model CALPUFF is in common use for industrial assessments in New Zealand. CALPUFF requires CALMET.
- CALMET makes use of meteorological observations, so is more realistic in the neighbourhood of the meteorological stations. And
- CALMET's computational requirements can be orders of magnitude smaller than those of TAPM, for the same spatial resolution. The nested CALMET runs were carried out at sub-km horizontal resolution, which is beyond the limits for which TAPM was designed.

To provide meteorological fields for data-sparse areas, TAPM was run on a series of nested grids; the coarsest covering most of New Zealand and the finest covering the Auckland region. All four grid areas are shown in Figure A.5. Two full years were modelled, namely 2005 and 2007. The parameters used for these model runs are shown in Table A.5, and apply to the meteorological component of TAPM. The pollution dispersion components of TAPM have not been used. All other input parameters took default values. Each one-year period was divided into six two-monthly runs.

The finest grid, at 1 km horizontal resolution, covers Auckland metropolitan urban limits (50 km x 82 km), with the 2.5 km grid covering the Auckland region (125 km x 205 km). Outputs from TAPM were compared with observations from selected meteorological sites, and with the 900 mb, 750 mb and 500 mb pressure levels of the Whenuapai soundings. Results of the comparison are presented in Appendix B.

The TAPM comparison required extraction of surface results from the locations of the climate sites. Hourly profiles were also extracted over those sites for later use in CALMET. In addition, extra surface results and profiles were extracted from locations in TAPM between the climate sites and around the edges of the region. Locations of these extra TAPM profiles are shown in Figure A.6. The information (all TAPM profiles and extra surface data) was used to supplement the observations in the CALMET runs.

Table A.5

TAPM configuration parameters.

Parameter	Value
Start and end dates	1 January to 31 December, 2005 and 2007
Grid centre (Lat/Long, WGS84)	36°51.5' S, 174°44.0' E
Grid centre (NZTM)	(1754518, 5919441) (m)
No. of grids; no. of grid points in horizontal	4; 50 x 82
Horizontal grid-cell spacing	15 km, 6 km, 2.5 km, 1 km
No. of grid points in the vertical	25; from 10 m to 8000 m
Monthly deep-soil moisture (12 values, from Pukekohe)	0.37, 0.35, 0.34, 0.29, 0.36, 0.40, 0.41, 0.39, 0.38, 0.41, 0.31, 0.35

Figure A.5
TAPM grids at a resolution of 15 km (top left), 6 km (top right), 2.5 km (bottom left) and 1 km (bottom right). Terrain contour intervals are 100 m, 100 m, 50 m and 50 m, respectively. Axes are in metres, NZTM.

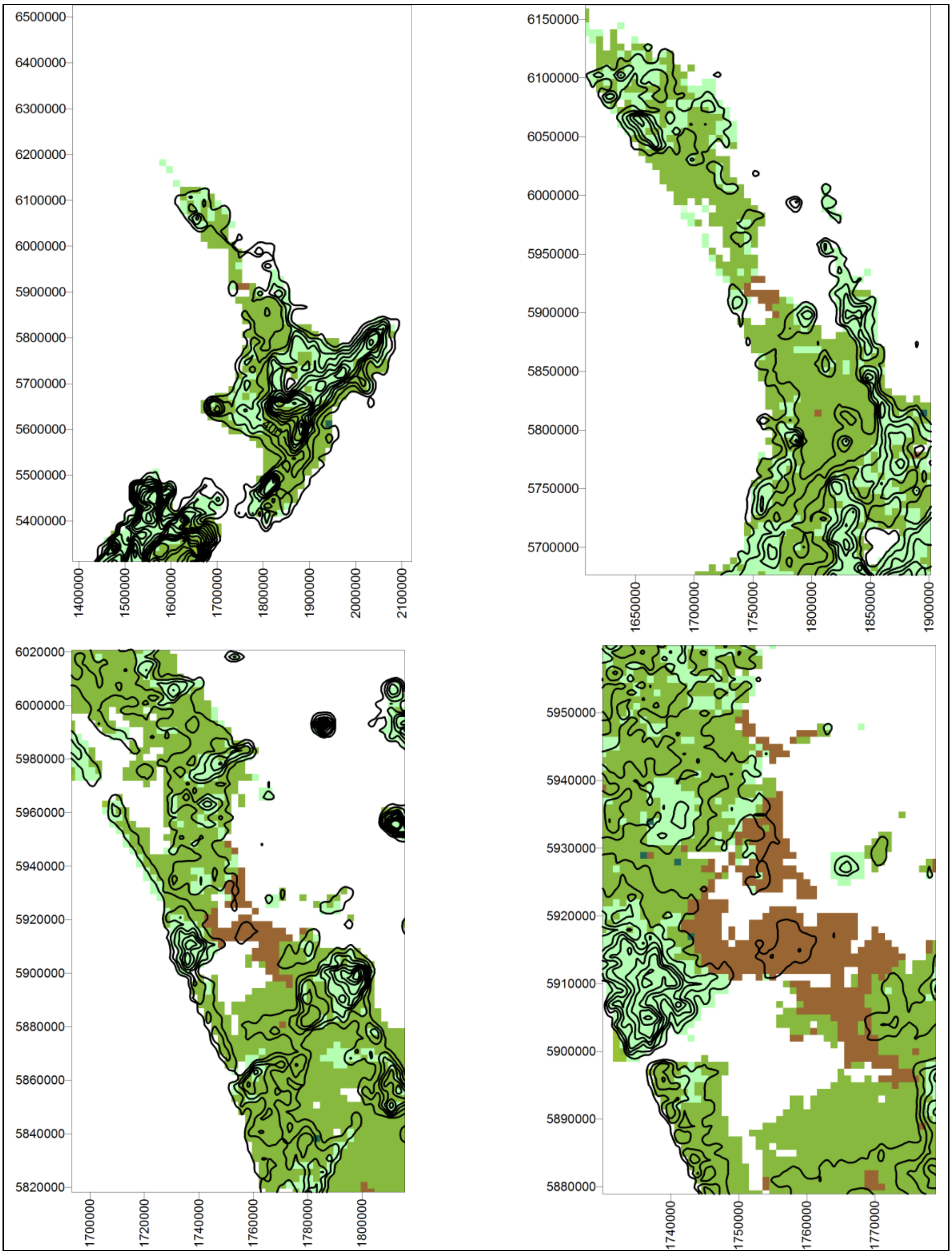
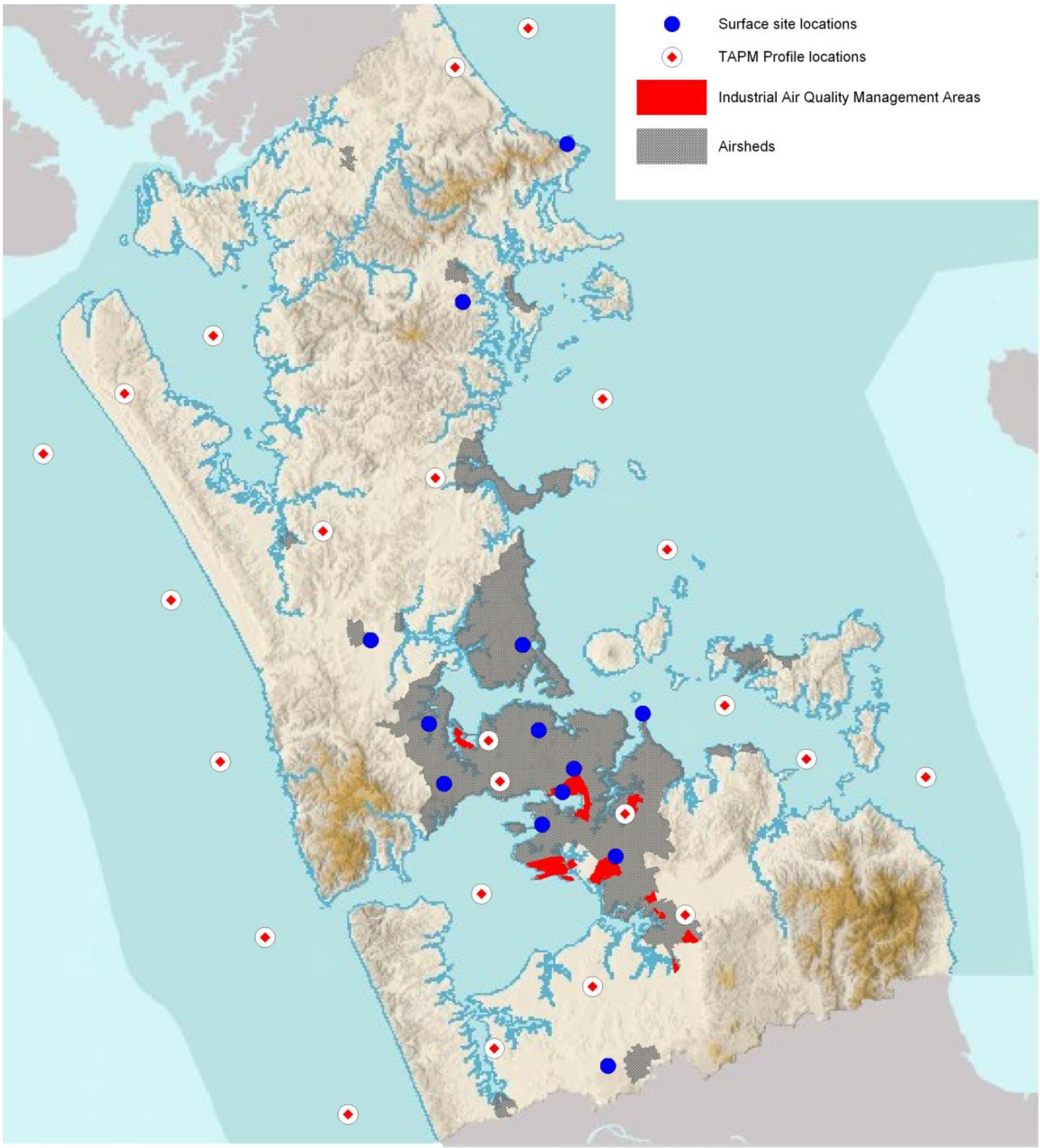


Figure A.6

Meteorological monitoring sites (blue circles) and extra profiles from TAPM (red/white circles) used for CALMET runs. Please check with the ARC or the Auckland Council after 1 November 2010 for the updated Industrial Air Quality Management Areas.



A.5.2 Stage 2 – regional CALMET modelling

A.5.2.1 Introduction

In addition to observed meteorological data and prognostic model results, spatial coverage data of land use and terrain comprise the other key inputs to CALMET. These are important for resolving the influence of land use changes and terrain effects on the meteorology. CALMET's boundary-layer and slope-flow development, as well as blocking and channelling of the wind by the terrain, respond to these inputs.

For the development of the meteorological datasets, land use and terrain information were provided by the ARC as GIS data, covering the extent of the Auckland region. This was done to ensure consistency of the CALMET model outputs with ARC data. The data were processed into gridded arrays using ARC-GIS Spatial Analyst software. Files in a format suitable for input to CALMET were created for each model run, covering several domains at differing horizontal resolution.

CALMET was run for each chosen year with a domain covering the Auckland region. This was done to capture terrain effects on the wind flow at a reasonable resolution, and provide the initial-guess fields for high resolution runs over specific smaller domains. CALMET was run for the 105 km x 135 km region at a horizontal resolution of 1 km, to capture the main three-dimensional features of the wind flow, such as orographically forced flows and sea breezes. The procedure for producing the regional CALMET dataset described in sub-stages, labelled 2A, 2B and 2C.

A.5.2.2 Stage 2A – surface-data CALMET run

The combination of model profiles from TAPM and surface observations as inputs to CALMET can lead to unrealistic results when those inputs are different from each other. This is seen readily if neighbouring sites have different wind directions, which could often be the case if one is from TAPM and the other from observations. A "bulls-eye" in the wind field arises, due to a sharp change in conditions between the TAPM-influenced site and the observation-influenced site.

The bulls-eye effect may appear at all levels. The surface observations are extrapolated vertically by CALMET using Monin-Obukhov similarity theory (MOST, the default option). The TAPM profile includes all levels.

Ideally, the CALMET fields would be determined mainly by the observations near to the surface, and the TAPM profiles at upper levels, with a smooth transition in between. Unfortunately, there is no combination of input parameters in CALMET which will allow this to happen, and the transition can occur abruptly.

A smooth transition has been achieved by merging two profiles from each meteorological site. Their relative weighting changes smoothly with height, from the surface-based profile to the TAPM profile (for the same location) at upper levels. The resulting blended profile can then be input to CALMET as upper-air data. This is done for every hour of each run. The profile blending is discussed in more detail in Section A.5.2.3.

The most straightforward way to produce the surface-based MOST profile is to run CALMET, use its vertical-extrapolation algorithm and extract profiles above the surface observation sites. This means that CALMET is run twice over the same domain, with some processing carried out between runs. The procedure has been the subject of research, in order to determine the parameters needed by CALMET, and the best way that the processing should be carried out. The results have been reported by Golder and others (Golder, 2007) as part of the FRST (Foundation for Research, Science and Technology) programme "Protecting NZ's Clean Air". The report also discusses the use of TAPM and describes suitable model performance evaluation techniques. In the following, the initial CALMET run is labelled the "surface-data" run; the final CALMET run is labelled the "blended-profile" run.

Tables D.1 to D.5 in Appendix D describe the configuration of the surface-data run. For this, CALMET has been run over a domain covering the Auckland region, driven by meteorological data from the stations listed in Section A.3.3. Upper-air profiles were provided by TAPM. These were located close to, but not coincident with, sites whose vertically-extrapolated profiles were to be blended with TAPM's upper-air results. The upper-air profiles were not situated over a surface-data site, as this would distort the profiles extrapolated above that site using MOST.

A.5.2.3 Stage 2B – blending TAPM and CALMET vertical profiles

The surface-data CALMET run produced meteorological profiles based on the vertical extrapolation of surface data from the sites listed in Table D.4 of Appendix D, according to MOST (option IEXTRP=-4). As TAPM is not expected to match the observations at the surface hour-by-hour, differences may occur between TAPM results and observations at the surface. The MOST profiles were blended according to height with the TAPM profiles, as a processing step after the surface-data CALMET run. The method is described by Golder (2007), and outlined below.

By merging the TAPM and MOST profiles from each meteorological site, new profiles were derived, which changed smoothly from MOST at the surface to TAPM at upper levels. The resulting blended profile was then input to CALMET as upper-air data. This was done for every hour of the run. The blending procedure was applied to the wind velocity components and temperature, and the results of the blending process are upper-air files for CALMET at the locations of the climate sites. The CALMET profiles were interpolated vertically onto the TAPM levels, before the blending process, so that the pressure profile from TAPM could be retained.

The meteorology matches the observations at the surface, but matches the TAPM profiles at upper levels (above the mixing height). The transition levels have been chosen as follows:

- TAPM profiles were used above the mixing height, h.
- CALMET profiles were used up to h/10 (or 20 m, whichever was larger). And

- Between h/10 and h, the meteorological parameters are weighted between TAPM (factor α) and CALMET (factor (1 – α)). The weighting factor α varies linearly with height, from 0 at h/10, to 1 at h.

The CALMET profiles were retained to one-tenth of the mixing height, as MOST only applies to the surface layer, rather than the whole of the boundary layer. The minimum height of the surface-layer was chosen as 20 m, which is the depth of the lowest CALMET model layer. In addition to the blended profiles, additional profiles from the TAPM runs were converted into the "UPDAT" format at locations in data-sparse areas (no blending was needed for these sites).

A.5.2.4 Stage 2C – blended-profile CALMET run

The blended-profile CALMET run differed from the surface-data CALMET run in the following respects:

- Surface-data and upper-air profiles were co-located, consisting of:
  - Surface observations and blended profile; or
  - Surface results and profile both from TAPM for data-sparse areas.
- Input parameters were chosen so as to prevent vertical extrapolation, as this was carried out following the procedure in Section A.5.2.3.

Tables D.1, D.2, D.6, D.7 and D.8 of Appendix D list the model input parameters used for this final stage of the regional-scale modelling with CALMET. Tables D.1 and D.2 are the run control and grid control parameters, which are the same as for Stage 2A. Tables D.7 and D.8 are the final blended-profile site locations, listed separately as surface and upper-air sites in CALMET, but co-located. Table D.6 contains the extrapolation parameters, which are different from Stage 2A.

The results of Stage 2C constitute an hourly, three-dimensional meteorological dataset, based on surface observations from Auckland, smoothly blended with profiles from TAPM, and supplemented with complete profiles from TAPM at extra locations away from the city centre where the surface measurements are made. This dataset is used as a three-dimensional initialization of the high-resolution CALMET runs, described in the next section.

A.5.3 Stage 3 – high resolution CALMET modelling

A.5.3.1 Modelling requirements

The blended-profile CALMET run is too coarse to resolve the effects of complex terrain on the meteorology in the areas of interest for industrial or transport assessments. These areas constitute small portions of the whole region. Hence high-resolution CALMET datasets have been developed nested within the region wide CALMET dataset.

The nested-run approach uses the coarser-grid CALMET outputs as hourly, three dimensional initial guess fields. This approach has the advantage that terrain effects at the coarser resolution are included in the initial-guess fields, even if they are due to topography outside the fine-resolution domains. Therefore, the fine-resolution results should be an improvement over a "non-nested" approach.

High resolution nested CALMET datasets have been developed for the areas of interest listed below. Their domain sizes and horizontal resolutions have been determined using three criteria:

- The area includes key discharge points, and a 2.5 km border around these (this is sufficient for industrial discharges, and more than sufficient for transport corridors).
- The grid should sufficiently resolve the local terrain (at a sub-km horizontal resolution).
- Eventual file sizes and CALPUFF run times should be manageable under reasonable computing power.

The areas of interest indicated by ARC and NZTA, used in targeting the location of high resolution CALMET domains, are listed as follows:

ARC Areas of Interest

- Wiri
- Onehunga
- Mount Wellington
- Penrose
- Avondale Isthmus
- East Tamaki
- Mangere/Airport

NZTA Areas of Interest

- Northern Motorway Extension
- Waterview Connection
- State Highway 20

The areas of interest for the ARC are primarily driven by the Industrial Air Quality Management Areas (IAQMA) in the Proposed Auckland Regional Plan: Air, Land and Water, which are the key industrial areas of the Auckland region and therefore locations targeted for such activities under the Regional Plan. The NZTA areas of interest are locations being considered by NZTA for upgrading of the highways network in the Auckland region.

A.5.3.2 Model domain locations and sizes

The approach for selecting the high-resolution CALMET model domains involved a desktop GIS study to determine suitable domain sizes that would reasonably cover the above areas of interest. The resulting nine model domains are shown in Figure A.7, bounded by the 1 km TAPM domain, the regional CALMET domain and the 2.5 km TAPM domain. The domains are numbered, increasing from north to south. The domains include IAQMAs, where industrial activities are concentrated. These are shown in Figure 5.1. Areas of interest for NZTA include the northern motorway (passing through domain H1) and the Waterview connection (passing through domain H4, see Figure 5.1 also).

In order to include all the IAQMAs, peripheral industrial areas and surrounding sensitive locations (such as residential areas) a model domain size of 10 km x 10 km has been chosen. The exception is the northern motorway extension (domain H1). The areas are overlapping to ensure all areas of interest are covered by at least one high resolution domain. Where a site falls within more than one model domain, the model domain in which it is most centrally located should be used.

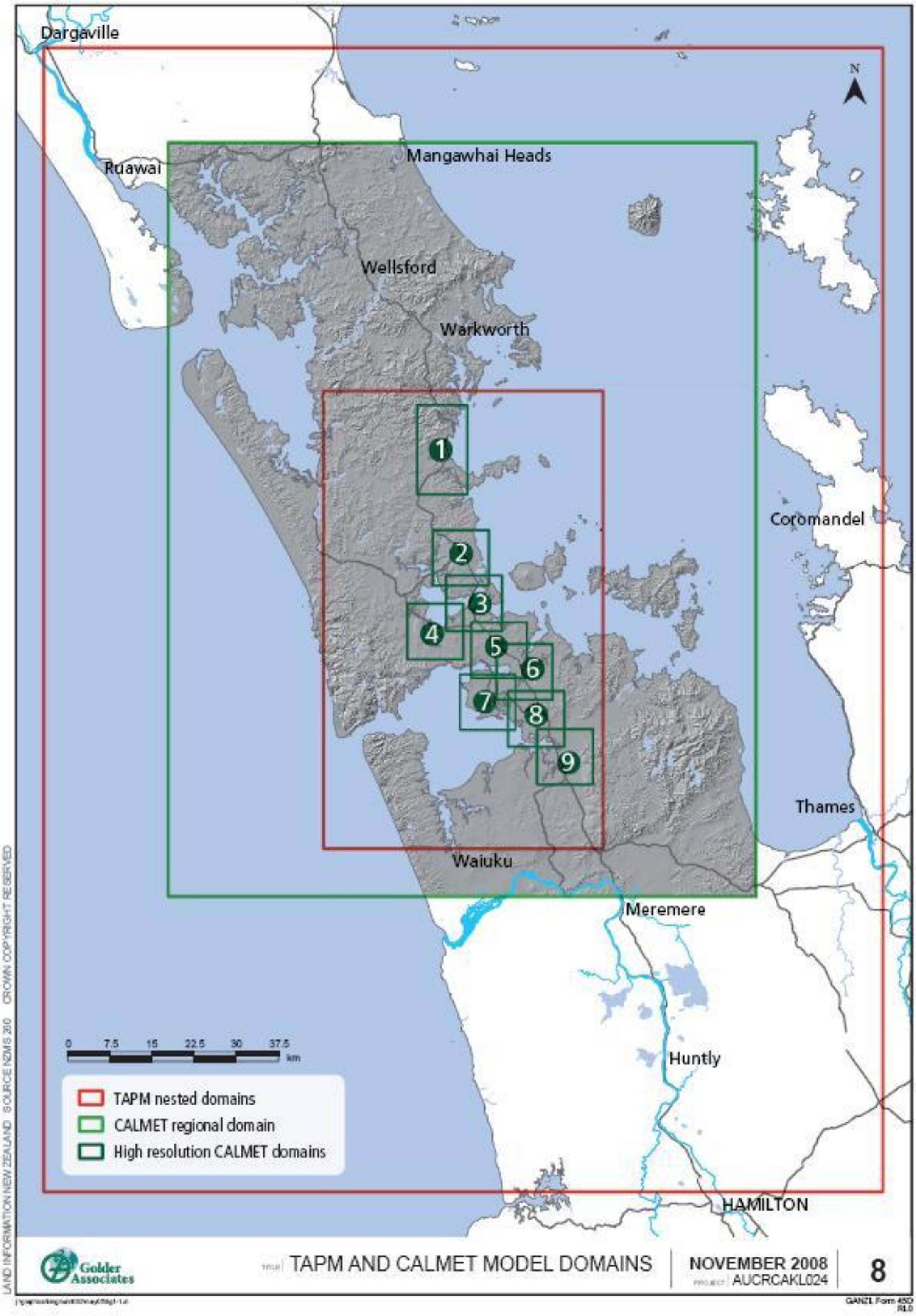
Using a 10 km x 10 km model domain size has allowed, in some cases, for several areas of interest to be contained within a single model domain (e.g. the Waterview connection and the Avondale isthmus, domain H4). This has resulted in fewer model domains being necessary to cover those areas of most interest to both ARC and NZTA, and has allowed for two additional domains being possible that include the Waitamata Harbour port area (domain H3, including the Harbour Bridge and Chelsea Sugar factory) and areas of North Shore City where some large or significant industrial activities are located (domain H2). These two areas also include the northern motorway, which may be important for any future motorway developments in those areas. In summary, the high-resolution CALMET domains are listed in Table A.6.

Table A.6

High-resolution CALMET domains.

Label	Name	Size
H1	Orewa	9 km x 16 km
H2	North Shore	10 km x 10 km
H3	Waitemata Harbour	10 km x 10 km
H4	Avondale	10 km x 10 km
H5	Penrose/Onehunga	10 km x 10 km
H6	East Tamaki	10 km x 10 km
H7	Mangere	10 km x 10 km
H8	Wiri/Manukau	10 km x 10 km
H9	Papakura	10 km x 10 km

Figure A.7
TAPM and CALMET model domains.



A.5.3.3 Model-domain resolution and data-file size

When determining the CALMET model domain resolution, the primary consideration should be resolving the local terrain and land use features which are likely to affect the meteorology. In practice, technical constraints such as the required domain size, computer processing ability and the size of output files generated can also be considerations in the determination of the model domain size and resolution.

We have selected the horizontal data resolution by comparing land use and terrain at different resolutions. Resolutions of 100 m and 200 m are discussed here. Any finer resolution than 100 m has been ruled out due to very large file sizes for a 10 km by 10 km area.

Examples of terrain and land use data at 100 m and 200 m resolution are shown in Figures A.8 and A.9 for domain H5 covering Penrose/Onehunga. Figure A.8 shows that the 100 m resolution resolves terrain features more finely, but does not identify any additional features over the 200 m resolution data. This indicates that either resolution is adequate for terrain, and 200 m could be chosen. However, Figure A.9 shows that there are several features in the 100 m resolution data that are less well defined in the 200 m data. Therefore, the 100 m resolution geospatial data were used for the high resolution model domains.

The high-resolution datasets have been generated from CALMET runs 'nested' within a larger, low resolution, regional CALMET dataset. The advantage of this approach is that the initial guess of the high-resolution CALMET solution is provided by the final fields of the coarse-resolution dataset, rather than simply interpolating between observations or prognostic-model results. Using this approach, larger-scale meteorological features are incorporated into the high-resolution solution. These may be driven by terrain features beyond the boundary of the high-resolution domain, and would be missed if the nested approach were not followed. Moreover, this approach should lead to a better solution in cases where there are no meteorological observations within a high-resolution domain with which to initialize that particular run.

The size of files generated by the CALMET runs depends on the number of grid points in the domain, so depends on the inverse-square of the grid spacing (that is, if the grid spacing is halved, the file size quadruples). The total file space required by the regional-scale CALMET runs is 27 GB per year of run. For each high-resolution run (of 10 km x 10 km), the file space required is 19 GB per year of run. The full CALMET dataset occupies approximately 415 GB (comprised of 27 GB per regional domain per year, 19 GB per 10 km x 10 km domain (eight of them), 28 GB for domain H1, each of these for 2 years).

Figure A.8

Comparison of 100 m (left) and 200 m (right) horizontal terrain resolution for Penrose/Onehunga high resolution domain (10 km x 10 km).

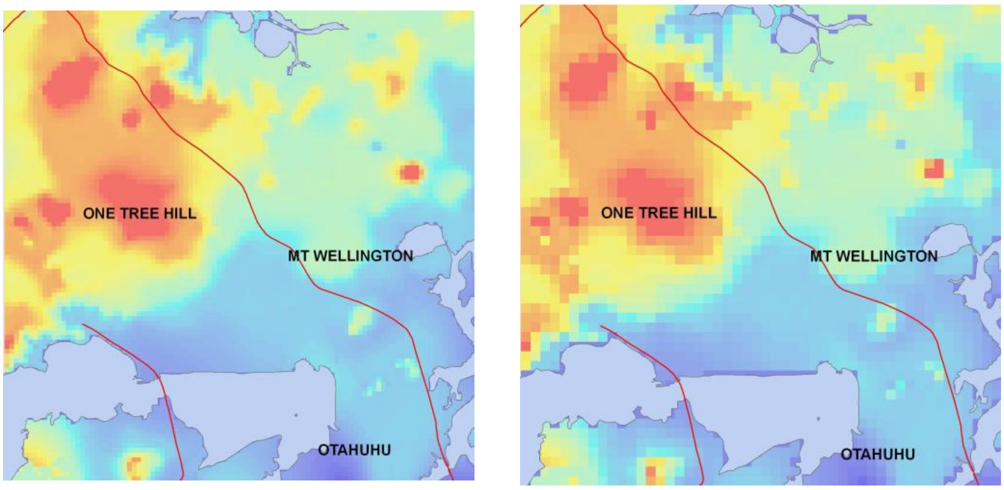
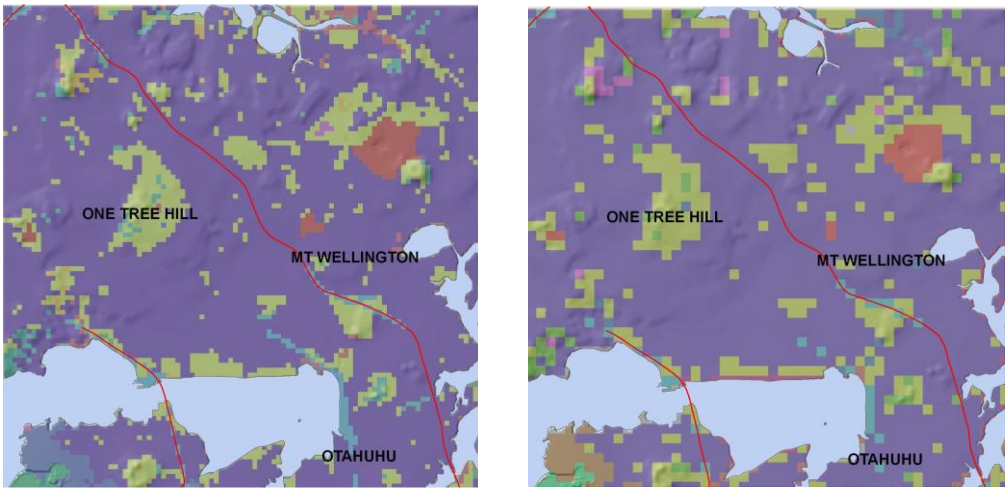


Figure A.9

Comparison of 100 m (left) and 200 m (right) horizontal land use resolution for Penrose/Onehunga high resolution domain (10 km x 10 km).



A.5.3.4 CALMET model configuration

Although the procedure for producing the regional-scale blended-profile run is non-standard, the procedure for the high-resolution nested runs follows standard methods, using more default parameter values. For instance, vertical extrapolation above surface stations using MOST is the chosen option, rather than a suppression of extrapolation in favour of use of the blended profile directly. This option is chosen as the blended profiles are based on lower resolution information from TAPM, which may not be appropriate in higher-resolution terrain, and it is more in line with common usage of CALMET.

The terrain radius of influence is set at 2 km, and the observation radii of influence (R1 and R2) are set at 500 m. Other parameters take default values, and the main difference between each high-resolution run is the domain location and underlying terrain map. The grid control parameters (defining the location and resolution of each domain) are listed in Chapter 5.

For convenience, the surface and upper air input files developed for the blended-profile have been used in the high-resolution runs. However, sites which are off-domain have been moved where appropriate so that they have no influence (this is necessary if the terrain is complex, as the intervening terrain is not seen in the high-resolution run).

A.5.4 Stage 4 – generation of single-point datasets for plume models

A.5.4.1 Introduction

AUSPLUME, CALINE4 and AUSROADS are steady-state Gaussian-plume models, which require meteorological information as inputs. This information includes measured parameters such as wind speed, wind direction and temperature, and derived parameters such as the mixing height and Pasquill-Gifford (PG) stability class. CALMET calculates all of these parameters, and they have been extracted from CALMET's high-resolution outputs at nine locations, listed in Table A.7 (note that two datasets have been extracted from domain H4, and none from H3). As explained in Section 5.3, these locations coincide with meteorological monitoring sites where possible, resulting in the AUSPLUME datasets containing observations from that location. Monitoring site locations have been used for datasets H2 (Takapuna), H5 (Penrose) and H8 (Wiri). For the rest of the domains, locations near to industrial or transport-project areas were chosen.

Table A.7

Locations of single-point datasets for Gaussian-plume models. Names of monitoring site locations, where used, are in parentheses.

Location	Dataset	NZTM Easting (km)	NZTM Northing (km)
Orewa	H1	1748.114	5947.895
North Shore (Takapuna)	H2	1756.059	5928.077
Avondale	H4A	1748.866	5917.402
Waterview	H4B	1751.822	5917.859
Penrose/Onehunga (Penrose)	H5	1761.751	5914.176
East Tamaki	H6	1768.235	5910.204
Mangere/Airport	H7	1759.169	5902.944
Wiri/Manukau (Wiri)	H8	1766.415	5904.322
Papakura	H9	1773.520	5896.547

A.5.4.2 Meteorological parameters

Although the meteorological parameters needed for plume models are provided by CALMET, there are several methods for calculating mixing height and PG stability class. There may be restrictions on these parameters (and possibly also the wind speed) with regard to their use in plume models. This section reviews those methods and compares them with the scheme used by CALMET.

A.5.4.2.1 Wind speed

Gaussian-plume models can overestimate contaminant concentrations when wind speeds are lower than about 0.5 m/s. In AUSPLUME, the wind speed should not be below this value. Recent versions of AUSPLUME (version 4 onwards) automatically increase the wind speed to 0.5 m/s whenever the input value is lower. This change has been applied to the wind speed extracted from CALMET for consistency of use in other Gaussian-plume models.

A.5.4.2.2 Pasquill-Gifford stability class assignments

CALMET assigns stability class using Turner's method (Turner, 1964), where cloud cover and solar angle determine the net radiation index, or insolation category. In combination with the wind speed the radiation index determines the stability class. The net radiation index is negative during the night and positive during the day, with the absolute value decreasing with increasing cloud cover (to more neutral conditions). A summary of stability assignments based on this method is shown in Table A.8.

We have compared the method with that used by VicEPA, the developers of AUSPLUME and AUSROADS. VicEPA uses a solar radiation method for daytime and a modified Pasquill-Gifford scheme for night-time to define stability class. A summary of the stability assignments is shown in Table A.9.

The two methods have similarities in their dependence on wind speed, solar radiation and cloud cover (as the radiation index is derived from sun angle and cloud cover). The matrix of stability classes looks similar in both tables with, for example, class A in the top-left for calm, sunny conditions.

The method used by VicEPA includes imposing class D before sunset and after sunrise, for all wind speeds. This is not explicitly done in the Turner scheme, but with a low sun angle (zenith angle less than 15o) at such times, the insolation category is 1 or 0. For category 1, the resulting stability class could be C under low-wind conditions.

It is important to note that the dependence of stability class on wind speed is slightly different between the Turner and modified Pasquill-Gifford schemes. As Gaussian-plume dispersion models (including AUSPLUME) generally base their lateral and vertical plume dispersion schemes on Pasquill-Gifford, the scheme used by CALMET to assign stability classes has been modified as a post-processing step, as follows:

- If the wind speed is less than 2 m/s, and the stability class is C, change the stability class to B.

- If the wind speed is greater than 3 m/s and the stability class is F, change the stability class to E. And
- If the wind speed is greater than 5 m/s and the stability class is E, change the stability class to D.

This leads to stability class assignments closer to the modified Pasquill-Gifford scheme, as used by VicEPA. The final stability classes used for the AUSPLUME datasets produced here are shown in Table A.10. Changes around sunrise and sunset have not been applied, and at low wind speed and low sun angle (insolation category 1) the stability class is now B.

Table A.8

Summary of stability-class assignments used by CALMET.

Wind Speed (m/s)	Net radiation index (insolation category)							
	4	3	2	1	0	-2	-1	0
0.5	A	A	B	C	D	F	F	D
1.0	A	B	B	C	D	F	F	D
1.5	A	B	B	C	D	F	F	D
2.1	A	B	C	D	D	F	E	D
2.6	A	B	C	D	D	F	E	D
3.1	B	B	C	D	D	F	E	D
3.6	B	B	C	D	D	E	D	D
4.1	B	C	C	D	D	E	D	D
4.6	B	C	C	D	D	E	D	D
5.1	C	C	C	D	D	E	D	D
5.7	C	C	C	D	D	D	D	D
6.2	C	D	C	D	D	D	D	D

Table A.9

Summary of stability-class assignments used by VicEPA.

Wind Speed (m/s)	Day time				1 h before sunset and after sunrise	Night time		
	Solar Radiation (W/m²)					Cloud cover		
	Strong >925	Moderate 675-900	Slight 175-675	Overcast <175		0-3 cloud	4-7 cloud	8 cloud
<2	A	A	B	D	D	F	F	D
<3	A	B	C	D	D	F	E	D
<5	B	B	C	D	D	E	D	D
5-6	C	C	D	D	D	D	D	D
>6	C	D	D	D	D	D	D	D

Table A.10

Summary of final stability-class assignments used in the AUSPLUME datasets. Entries differing from Table A.8 are highlighted and in bold red.

Wind Speed (m/s)	Net radiation index (insolation category)							
	4	3	2	1	0	-2	-1	0
0.5	A	A	B	**B**	D	F	F	D
1.0	A	B	B	**B**	D	F	F	D
1.5	A	B	B	**B**	D	F	F	D
2.1	A	B	C	D	D	F	E	D
2.6	A	B	C	D	D	F	E	D
3.1	B	B	C	D	D	**E**	E	D
3.6	B	B	C	D	D	E	D	D
4.1	B	C	C	D	D	E	D	D
4.6	B	C	C	D	D	E	D	D
5.1	C	C	C	D	D	**D**	D	D
5.7	C	C	C	D	D	D	D	D
6.2	C	D	C	D	D	D	D	D

A.5.4.2.3 Mixing height

The minimum mixing height in CALMET is set to 50 m. This is the default value and is recommended in the modelling GPG (MfE, 2004b). Mixing heights are calculated internally by CALMET using several schemes (according to time of day and dominance of convective or mechanical turbulence), ensuring that the result is not below 50 m.

However, as there is no check in CALMET of consistency between mixing heights and stability, there is a possibility that unreasonable combinations of these parameters will occur. The direct outputs from CALMET give many hundreds of neutral or unstable hours per year with a mixing height below 100 m. Under such stability conditions it is not physically reasonable to expect the dispersion of discharged pollutants to be confined within such a shallow layer. Therefore, a minimum mixing height has been set for each stability class, as a post-processing step, as shown in Table A.11.

The chosen minimum mixing heights under neutral and unstable conditions (classes A-D) would be considered by most air quality practitioners to be at the lower end of the range expected for those stability classes. Under neutral conditions, with higher wind speeds, shear-driven turbulence would occur in a layer much deeper than 100 m. Likewise, under unstable convective conditions, the mixing layer may reach 1 - 2 km in depth in the middle of a summer day. Therefore, "average" mixing heights would be higher than those presented in Table A.11. However, as mixing heights could conceivably be as low as the values given in the table, those values have been chosen for the AUSPLUME datasets so that dispersion modelling would yield conservative results – that is, results which are worst-case, but still reasonable.

Table A.11

Minimum mixing height, as a function of stability class.

Stability class	Minimum mixing height
A	300 m
B	200 m
C	100 m
D	100 m
E	50 m
F	50 m

A.5.4.2.4 Summary

Boundary-layer parameters, such as surface wind, stability class and mixing height, have been extracted from the high-resolution CALMET datasets and converted into a format compatible with Gaussian plume models. Some adjustments to those parameters have been made as post-processing steps, as described in the previous section. These have been made to ensure consistency between the parameters and to provide AUSPLUME meteorological files which would lead to reasonable, but conservative, dispersion model results. It should be noted that their use is envisaged for different levels of assessment. AUSPLUME may be used in a Tier 2 screening assessment, where conservative model results should be expected. If the model predictions indicate an exceedence of relevant air quality standards or guidelines, then a refined assessment (Tier 3) would be carried out using CALMET/CALPUFF.

The AUSPLUME datasets have been examined using the "Starmet" utility, developed by Terry Brady Consulting Limited. This utility checks for consistency between wind speed, stability class and mixing height for each hour of data. The minimum mixing heights listed in Table A.11 for each stability class are the default values used in Starmet.

A.5.4.3 AUSPLUME

The AUSPLUME meteorological file contains a row of data for each hour. Each row contains the year, month, day, hour, temperature, wind speed, wind direction, stability classification and mixing height, which have been extracted from CALMET outputs.

There are several optional parameters, namely, wind-direction variability ($\sigma\theta$), wind profile exponent, potential temperature gradient, precipitation code and precipitation data, friction velocity and Monin-Obukhov length. These are required for simulation of chemistry and wet deposition. However, they have not been incorporated into the AUSPLUME datasets, and if these processes need to be modelled, it is recommended that CALPUFF be used.

A.5.4.4 CALINE4 and AUSROADS

CALINE4 simulates a single hour of dispersion per run, and therefore requires an input file for each hour. The input file contains road-link descriptors, emission rates, receptor locations and the meteorology of that hour. Meteorological information appear in a single line, containing wind direction, wind speed, PG class, mixing height, $\sigma\theta$, ambient pollution level and temperature.

AUSROADS is based on the algorithms of CALINE4, and is able to simulate a whole year in a single run. All of the meteorological information is contained in single file, identical to that required by AUSPLUME, which we have created for each area of interest. We have provided meteorological files compatible with AUSPLUME and AUSROADS, but leave it to the user to split these into separate files for each hour for use with CALINE4, as they need to be combined with the other information unrelated to the meteorology.

CALINE4 requires the wind-direction variability. This may be derived according to stability class, using the formulas recommended by Hanna, Briggs and Hosker (1982), as shown in Table A.12.

Table A.12

Sigma-theta (σ_θ) values according to PG stability class. These are derived from the formula for σ_y, dividing by downwind distance.

PG Class	σ_θ (radians, rural)	σ_θ (degrees, rural)	σ_θ (radians, urban)	σ_θ (degrees, urban)
A	0.22	12.6	0.32	18.3
B	0.16	9.2	0.32	18.3
C	0.11	6.3	0.22	12.6
D	0.08	4.6	0.16	9.2
E	0.06	3.4	0.11	6.3
F	0.04	2.3	0.11	6.3

Appendix B: Performance evaluation of TAPM and CALMET

B.1 Quality control and model performance evaluation

B.1.1 Introduction

In principle, TAPM and the regional-scale CALMET model runs are intended to give a picture of the regional and mesoscale meteorology, including local wind flows such as land- and sea-breezes on scales of a few kilometres. TAPM should simulate these, and their signature passed into the CALMET simulation through the incorporation of surface results and profiles from the prognostic model. Then it is up to the high-resolution CALMET runs to produce realistic terrain-induced flows at the sub-kilometre scale, as well as blending observations from meteorological stations with the TAPM outputs. Note that some of the high-resolution domains do not contain meteorological stations, and the final model solution relies on a good representation of terrain flows.

In addition to checks on TAPM and CALMET, the AUSPLUME outputs using the extracted meteorological datasets were compared with those using the previous meteorological datasets. Details of the comparison are contained in Appendix C.

The following list of checks is appropriate to ensure good model performance and good-quality final results, and these are discussed in subsequent sections of this Appendix, or in other Appendices:

- Section B.1.2: Demonstration of realistic flows in TAPM, such as sea breezes and slope flows.
- Section B.1.3: Quantitative performance evaluation of TAPM.
- Appendix A: Quality control of meteorological and geographical information prior to input to CALMET.
- Section B.1.4: Qualitative assessment of CALMET outputs, checking for realistic terrain flows and realistic influences of meteorological observations on the surroundings of the weather stations. And
- Appendix C: AUSPLUME comparison.

B.1.2 Flow patterns produced by TAPM

Like any prognostic model, TAPM solves mathematical equations for meteorological flows. The model is used here to simulate the meteorology over New Zealand as a whole, with a specific focus at high resolution on the Auckland region. The flows are driven by the meteorology at larger scales than that of New Zealand, and topographical and thermal contrasts. Prognostic models generally produce good land-sea breezes in idealised conditions, and the study of these features was one of the earliest research uses of the models. Land-sea breezes were a good test of the high-resolution model capabilities. The resolution was (and generally still is) higher than that used for operational weather forecasts, so prognostic models were used as research tools in idealised conditions, which were without large-scale forcing. In the absence of large-scale forcing (for instance, if the near-surface conditions are quite calm under a large-scale anticyclone), prognostic models can easily produce sea breezes. Over the Auckland isthmus, opposing sea breezes have been demonstrated in prognostic models (McKendry, 1989; 1992).

In the TAPM runs, the situation is complicated by the presence of large-scale forcing, as TAPM attempts to simulate the wind and weather patterns realistically from day to day. Effects of land/sea thermal forcing are superposed on the large-scale flow, and the idealised situation of opposing sea breezes does not often happen. However, sea breeze fronts (sharp changes in wind direction) do occur, and are mobile as conditions change, crossing the isthmus during the day. Also, detail is seen in the model results whereby sea breezes can radiate out over the shores surrounding the Manukau Harbour.

Figures B.1 and B.2 show an example of opposing sea-breezes in the TAPM results, which occurred in the model on 20 November 2007. At 0600, the flow at the surface is generally from the south, and more rapid over the sea (Figure B.1(a)). The flow is also diverted by the Waitakere ranges, stagnating on the upwind side, diverting around and accelerating along the downwind slopes. In the more stable night-time conditions, the wind does not blow directly over terrain obstacles, but can be blocked by them. A similar process appears to be occurring in the south-east of the domain, with a downslope southeasterly wind. This is the finest TAPM grid, at resolution 1 km, and the southeasterly flow is being driven by the terrain on the parent grid (2.5 km resolution).

The wind is less strong at the 1000m level at this time, and is from the south or southeast (Figure B.2(a)). By the afternoon, the wind direction has changed at all locations at the surface, with opposing breezes converging along the isthmus (Figure B.1(b)). At the same time, there is some divergence aloft, away from the convergence line (Figure B.2(b)). This example exhibits expected features of sea breezes – change of wind direction to blow from sea to land, and divergence aloft – and so is probably a local thermally-forced feature, rather than simply a change in the large-scale conditions. The breezes are superposed on a large-scale southeasterly.

Figure B.1
TAPM wind field – lowest model level (10 m above ground). Day 22 (20 November 2007). (a) 0600 NZST (left); (b) 1500 NZST (right). Every second wind vector is shown.

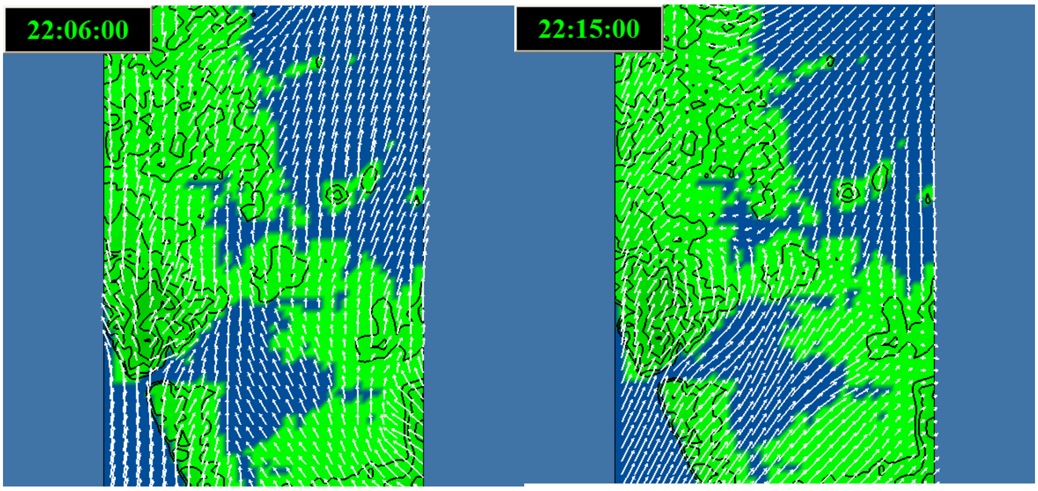
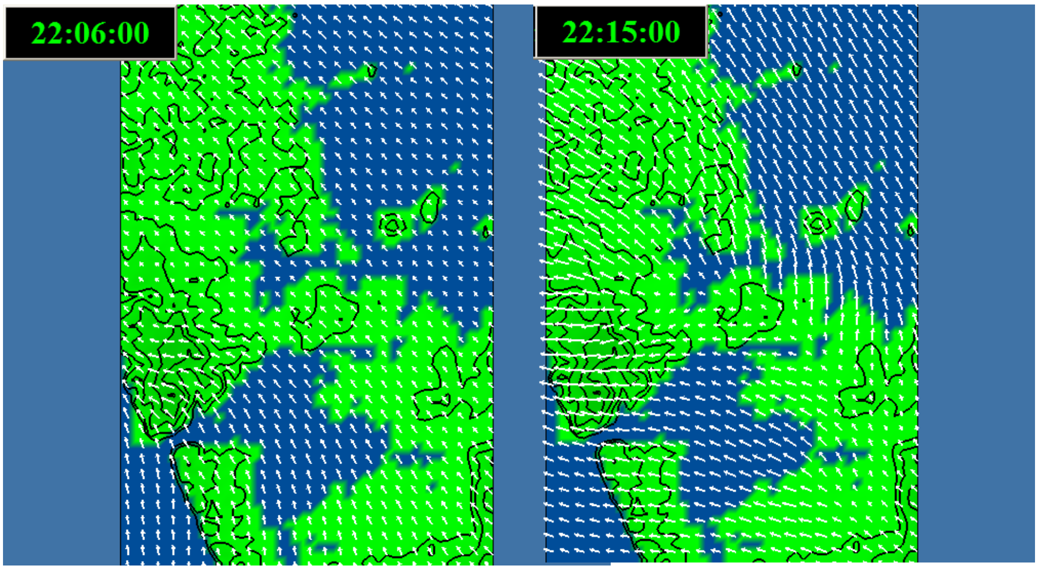


Figure B.2
TAPM wind field – model level 1000 m above ground. Day 22 (20 November 2007). (a) 0600 NZST (left); (b) 1500 NZST (right). Every second wind vector is shown.



B.1.3 Statistical performance of TAPM

Time series of TAPM outputs at several sites have been compared with data from those sites using common statistical measures. Model performance measures are described by Willmott (1982) and some are summarised in the Appendices of Golder (2007). The TAPM outputs have been compared with 12-hourly profiles from

Whenuapai at several heights, with the ARC meteorological data from ambient air quality monitoring sites, and with other sites from CliDB.

The index of agreement (IOA) varies between 0 for no agreement and 1 for full agreement between modelled and observed quantities. This quantity is shown for the wind-velocity components U and V, and temperature and relative humidity in Table B.1. Most comparisons have values over 0.9, and all are above 0.8. This should be considered good agreement for a meteorological model, but note that this is a statistical measure of a whole series of data which does not describe how well extremes are modelled.

Table B.1

The index of agreement (IOA) between TAPM outputs and meteorological observations for the 2005 TAPM run.

Site	U	V	Temp	RH
Whenuapai_26m	0.91	0.88	0.93	No data
Whenuapai_300m	0.96	0.94	No data	No data
Whenuapai_925mb	No data	No data	0.97	No data
Whenuapai_850mb	0.96	0.96	0.92	No data
Whenuapai_700mb	0.98	0.96	0.98	No data
Khyber Pass	0.91	0.90	0.94	0.84
Henderson	0.92	0.90	0.94	0.87
Takapuna	0.91	0.86	0.88	0.84
Musick Point	0.87	0.90	0.96	0.84
Penrose	0.84	0.88	0.94	0.84
Pukekohe	0.90	0.86	0.94	0.87
Onehunga	0.93	0.92	0.94	0.85
Wiri	0.93	0.91	0.95	0.85
Leigh 2	0.91	0.81	0.93	0.80
Whenuapai	0.91	0.90	0.92	0.84
Warkworth	0.92	0.90	0.90	0.85
Mangere	0.92	0.93	0.94	0.78
Auckland Airport	0.91	0.92	0.94	0.84

Other measures include the so-called "skill scores". "Skill_R" is the root-mean-square model error divided by the standard deviation of the observed parameter. It should be as small as possible (definitely less than 1), meaning that the model error is small compared to the observed variability in the parameter. Values of Skill_R are presented in Table B.2. These are all below 1, except for the V-component at Leigh.

Table B.2

Skill score Skill_R for the TAPM 2005 run.

Site	U	V	Temp	RH
Whenuapai_26m	0.52	0.68	0.47	No data
Whenuapai_300m	0.42	0.49	No data	No data
Whenuapai_925mb	No data	No data	0.35	No data
Whenuapai_850mb	0.39	0.40	0.59	No data
Whenuapai_700mb	0.29	0.36	0.32	No data
Khyber Pass	0.61	0.60	0.44	0.79
Henderson	0.50	0.57	0.43	0.67
Takapuna	0.65	0.72	0.62	0.76
Musick Point	0.71	0.62	0.36	0.78
Penrose	0.91	0.78	0.44	0.78
Pukekohe	0.73	0.91	0.44	0.63
Onehunga	0.54	0.54	0.42	0.74
Wiri	0.51	0.51	0.40	0.72
Leigh2	0.60	1.19	0.47	0.88
Whenuapai	0.50	0.59	0.49	0.68
Warkworth	0.48	0.66	0.53	0.68
Mangere	0.50	0.50	0.41	0.86
Auckland Airport	0.52	0.52	0.43	0.73

"Skill_V" is the ratio of the standard deviations of the modelled and observed parameters. It should be as close as possible to 1, meaning that the model variability in the parameter is similar to the observed variability. Values of Skill_V are presented in Table B.3, which are all reasonably close to 1.

These statistics show that TAPM performs well over the Auckland region. Although CALMET is primarily driven by observations, TAPM is used to provide upper-air profiles and some surface pseudo-sites. It is still important to evaluate the performance of TAPM, to ensure that its results are consistent with the observations with which it is being blended.

Table B.3
Skill score Skill_V for the TAPM 2005 run.

Site	U	V	Temp	RH
Whenuapai_26m	0.82	1.07	0.79	No data
Whenuapai_300m	1.03	1.11	No data	No data
Whenuapai_925mb	No data	No data	0.97	No data
Whenuapai_850mb	0.88	0.93	1.04	No data
Whenuapai_700mb	0.94	0.92	1.07	No data
Khyber Pass	1.06	0.92	0.84	0.98
Henderson	0.81	0.89	0.79	0.90
Takapuna	1.19	1.02	0.77	0.95
Musick Point	1.04	1.07	0.81	1.02
Penrose	1.38	1.36	0.78	0.98
Pukekohe	1.39	1.50	0.78	0.81
Onehunga	1.09	1.00	0.80	0.98
Wiri	0.94	0.77	0.82	0.94
Leigh2	1.02	1.83	0.81	0.96
Whenuapai	0.73	0.98	0.75	0.81
Warkworth	0.77	1.19	0.69	0.81
Mangere	0.83	0.91	0.74	0.88
Auckland Airport	0.80	0.89	0.73	0.92

B.1.4 Qualitative assessment of CALMET output

B.1.4.1 Regional-scale CALMET

As described in Appendix A, profiles and surface results are extracted from TAPM and blended with surface observations in the regional-scale CALMET run. This enables a realistic three-dimensional wind-field structure to be brought into the CALMET solution (which is used as the initial guess for the high resolution CALMET runs). Near the surface, some differences between the CALMET and TAPM solutions may be apparent, as CALMET incorporates measurements into the TAPM solution. Note that TAPM is designed to simulate realistic meteorological fields over a long period, say, a year, and is not expected to reproduce observed conditions exactly, hour by hour. However, as it is driven by large-scale meteorology from a forecasting model, into which a global set of observations has been assimilated, TAPM should perform well on the larger scale. Results presented in the tables above demonstrate good model skill at the regional scale.

The low-level flows in CALMET are shown in Figures B.3 and B.4, for the same hours as Figure B.1. The models match each other well at the earlier time (compare Figure B.1(a) with Figure B.3), although CALMET's results are arguably better over the higher terrain. By the mid-afternoon, the TAPM low-level wind field has been overridden by the observations, and the southwesterly wind component of the sea breeze has progressed further to the northeast, with the northeasterly wind component barely progressing onshore (compare Figure B.1(b) with Figure B.4). Upper-level flows from CALMET (not shown here) are similar to the TAPM fields, as the influence of the surface meteorology decreases with height.

In summary, the CALMET regional-scale solution builds upon the approximation supplied by TAPM, by superposing surface-based observations to improve the hour-by-hour meteorological fields and produce a three-dimensional initialization for the high-resolution CALMET domains.

Figure B.3

Regional-scale low-level wind fields from CALMET (exported from CALDesk) – equivalent to Figure B.1(a).

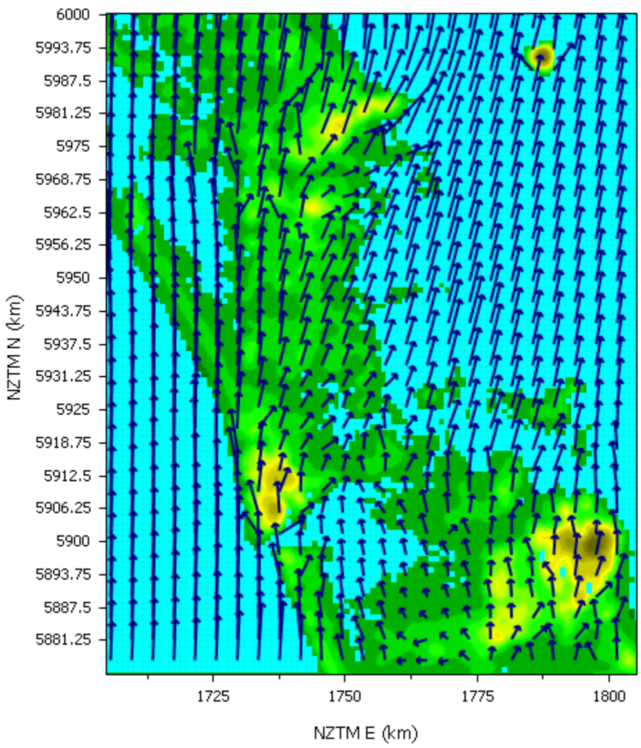
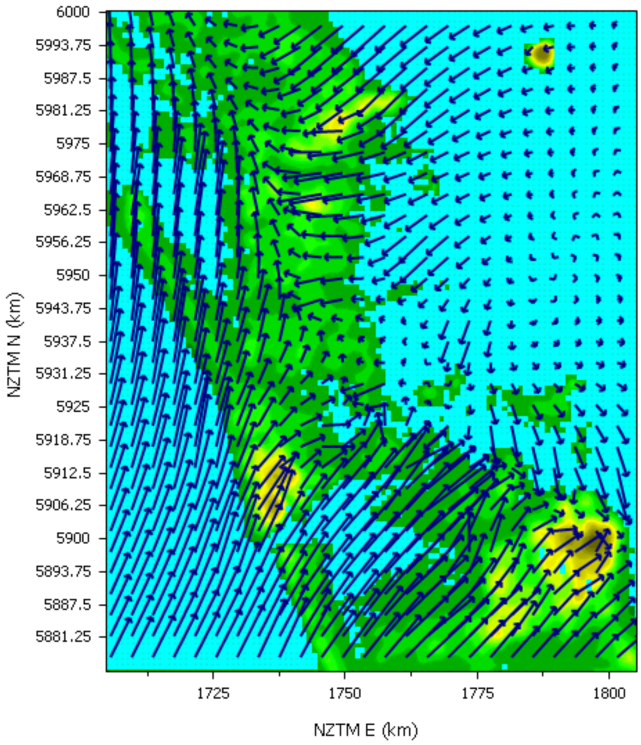


Figure B.4

Regional-scale low-level wind fields from CALMET (exported from CALDesk) – equivalent to Figure B.1(b).



B.1.4.2 High-Resolution CALMET Runs

There are several key input parameters to CALMET which need to be carefully selected to produce realistic results. These include 'radius of influence' parameters for the meteorological sites and for terrain effects. The site radius of influence should be made small, particularly if there is terrain close to the site. The meteorology would change close to nearby hills, and it is inappropriate to impose measured values there. Note that every grid point does not need to be within the radius of influence of a site, and increasing the radius of influence to make this the case can lead to a bland, unrealistic meteorological field, with no effects of terrain apparent. The radius-of-influence parameters in CALMET are applied at the later stages of the model's calculation for each hour, and the model results at the site are made to match the observations over a small area (They may already do so, if the model's initial guess has not been altered by the terrain). The radius of influence of the sites is 500 m in the high-resolution runs (this is the value given to parameters R1 and R2).

The process of choosing the terrain radius-of-influence parameter TERRAD is not so straightforward, and involves some sensitivity testing before a final choice is made. In complex terrain, TERRAD should be just over half the distance between successive peaks, so that terrain-induced flows interact with each other in the valleys. However, for isolated peaks, or for domains which have a mixture of hilly and flat areas, care should be taken. If TERRAD is too small, then the wind is unaffected by the terrain and blows directly over the hills, which is unrealistic during night-time. If it is too large, a slight undulation in the terrain – one invisible when drawing reasonably-spaced contours – may produce a large effect on the wind field when none should be visible.

For the high-resolution CALMET datasets generated here, a TERRAD value of 1 km was too small, and a value of 10 km too large. This can be seen in the following example. Figure B.5 shows a winter night-time example of surface wind from CALMET, with TERRAD set to 1 km. The main peaks (One Tree Hill and Mount Eden) are 3 km apart, but these are fairly isolated, and a flatter region extends around 7 km to the southeast of One Tree Hill. The wind speed varies, but apart from in the southwest corner, its direction is constant. There appears to be no terrain effects on the wind. Flow blocking by the hills or downslope flows would lead to changes in direction at the scale of the hills.

Figure B.5

CALMET low-level wind field – Penrose/Onehunga run, 17 June 2005 03:00. TERRAD = 1 km.

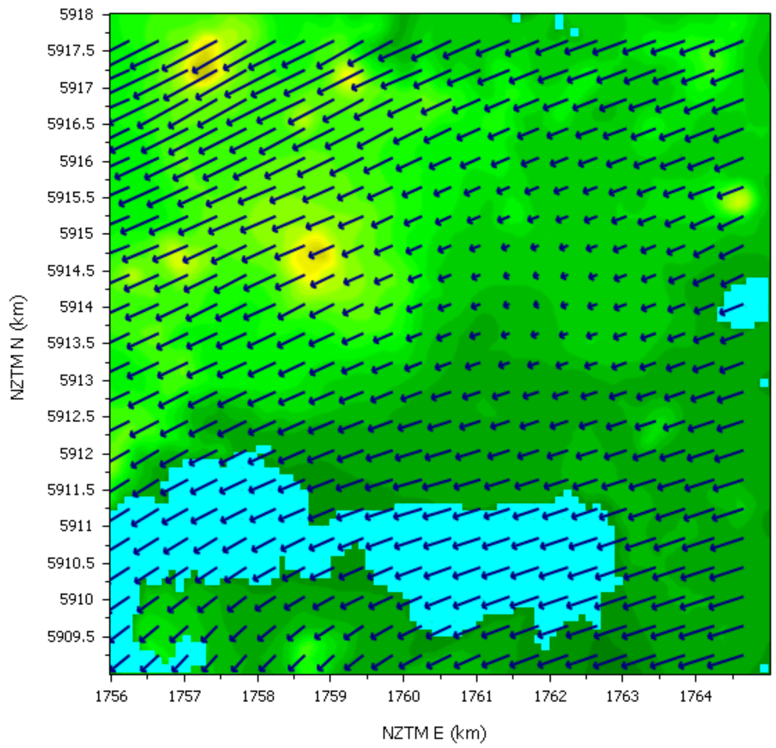
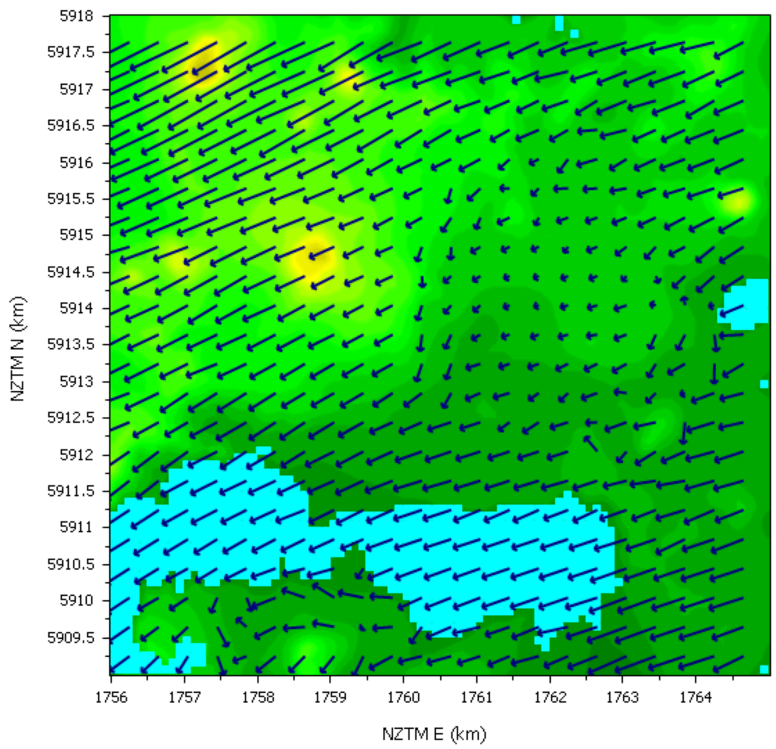


Figure B.6 shows the same hour from an equivalent run with TERRAD set to 10 km. In the southeastern part of the figure, the flow has been diverted to along the contours. As the terrain is not so steep, this is likely to be too large an effect. There is a lot of spatial variability in the wind field. This is reasonable over short periods, but the model fields are hour averages, which should be smoother. Note that there is little change over One Tree Hill and Mount Eden – over those locations the wind is more rapid and should therefore flow over the terrain.

Figure B.6

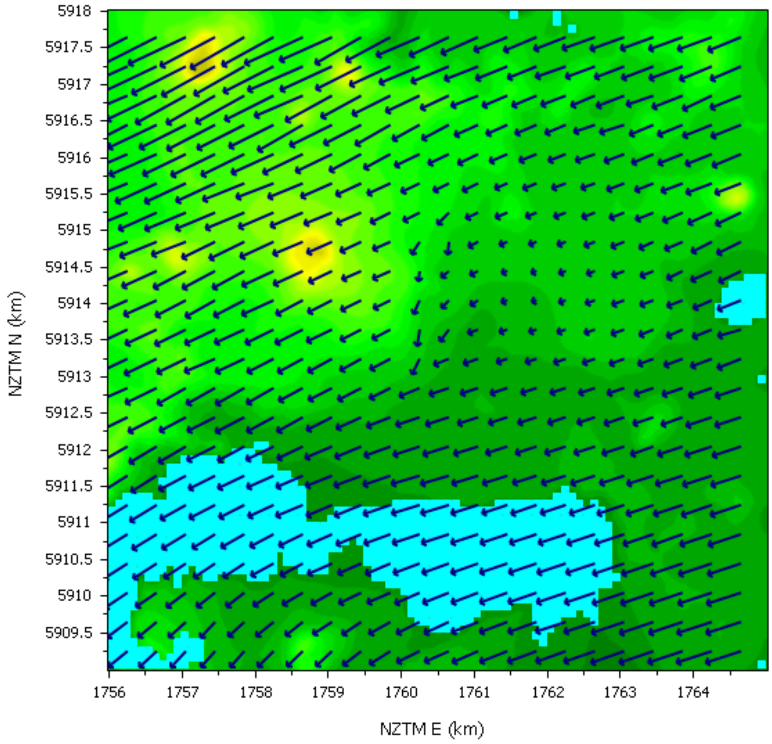
CALMET low-level wind field – Penrose/Onehunga run, 17 June 2005 03:00. TERRAD = 10 km.



In summary, TERRAD should be large enough to allow the terrain to affect the flow under lighter wind conditions, but not so large as to affect the flow over flatter terrain. Comparisons of several parameter values, and examining many hours of model results has lead to a suitable choice of TERRAD of 2 km. This leads to a diversion of the lighter winds around the flanks of the steeper hills but leaves the wind field fairly uniform over flat terrain. For the equivalent model time to Figures B.5 and B.6, the low-level wind is shown in Figure B.7. Coincidentally, this choice of TERRAD of 2 km is also suggested by the separation of the two main hills.

Figure B.7

CALMET low-level wind field – Penrose/Onehunga run, 17 June 2005 03:00. TERRAD = 2 km.



Appendix C: Comparison with previous AUSPLUME datasets

C.1 Introduction

A comparison of the AUSPLUME datasets for 2005 and 2007 developed through the present work with the previous datasets for 1996 and 1997 has been undertaken. As the 1996 and 1997 datasets were developed using data from Auckland airport, they have been compared with the 2005 and 2007 datasets from domain H7 (Mangere). The comparison examines the meteorological parameters in each dataset and carries out some simple dispersion-modelling tests using AUSPLUME.

A comprehensive review of the 1996 and 1997 NIWA datasets has not been possible, as documentation detailing their development could not be obtained. Instead, this comparison is designed to give the user an appreciation of any differences that might arise when undertaking dispersion modelling with newly developed 2005/2007 AUSPLUME datasets, compared with the 1996/1997 datasets. The ranges of meteorological parameters occurring in each have been compared (Section C.2), and an analysis of model predictions for four different discharge scenarios has been carried out (Section C.3).

C.2 Meteorological parameters

Summaries of the meteorological parameters for the datasets are presented in Tables C.1 to C.4. The frequency of occurrence of each stability class for each year is also shown in Figure C.1. It can be seen that the 2005 and 2007 datasets are quite similar to each other, and the same is true of the 1996/1997 datasets. However, there are differences between the 1996/1997 and 2005/2007 versions, which are summarised in the following list:

1) Stability classes
    a. The new datasets have a higher frequency of stability class B, and a lower frequency of class D. This is probably accounted for by cases of low sun angle and low wind speed (see Appendix A, Table A.10). Also, low wind speed cases of class C have been changed to class B.
    b. The new datasets have a higher frequency of stability class F.
2) Minimum mixing heights
    a. The previous datasets have a minimum mixing height of 50 m imposed, which is reached in neutral and stable conditions (classes D, E and F).

b. The new datasets have a more realistic (higher) minimum mixing height in neutral and unstable conditions, although they should still give conservative results (see Appendix A, Section A.5.4.2.3, Table A.11). The minimum mixing heights are reached under stability classes B, D and F.

3) The maximum mixing heights are greater under stable conditions in the new datasets than in the previous data sets.

4) A minimum wind speed of 0.5 m/s has been imposed for the new datasets, which is reached under stability classes A, B, D and F. No minimum was imposed for the previous datasets, although the minimum is set to 0.5 m/s at run-time by AUSPLUME.

5) The maximum wind speeds in stable conditions are lower in the new datasets. This is because the stability class is changed if the wind speed is too high under stable conditions, leaving a maximum of 3 m/s under class F and 5 m/s under class E.

The differences between the new and previous datasets are likely to be due to differences in approach or inter-annual changes in the meteorology. Some schemes impose stability class D (neutral) at sunrise and sunset. This was not done for the new datasets, and appears not to have been done for the previous datasets. The issue of stability at sunrise has been widely debated in NZ, and the consensus appears to be that class D at sunrise and sunset should not be imposed (leaving the stability class under low insolation as B or D, depending on the wind speed).

Table C.1

AUSPLUME 2005 dataset.

Stability Class	Definition	Stability class	Minimum mixing height (m)	Maximum mixing height (m)	Minimum wind speed (m/s)	Maximum wind speed (m/s)
A	Very stable	0.7%	563	1622	0.5	2.8
B	Unstable	12.2%	200	1738	0.5	4.9
C	Slightly unstable	10.3%	367	2474	2.0	10.5
D	Neutral	38.6%	100	3000	0.5	12.7
E	Slightly stable	13.7%	93	944	1.8	5.0
F	Stable	24.5%	50	381	0.5	3.0

Table C.2

AUSPLUME 2007 dataset.

Stability Class	Definition	Stability class	Minimum mixing height (m)	Maximum mixing height (m)	Minimum wind speed (m/s)	Maximum wind speed (m/s)
A	Very stable	0.7%	581	1526	0.5	2.8
B	Unstable	11.7%	200	1954	0.5	4.9
C	Slightly unstable	10.4%	320	2481	2.0	10.1
D	Neutral	40.5%	100	2710	0.5	11.2
E	Slightly stable	13.2%	91	892	1.8	5.0
F	Stable	23.5%	50	378	0.5	3.0

Table C.3

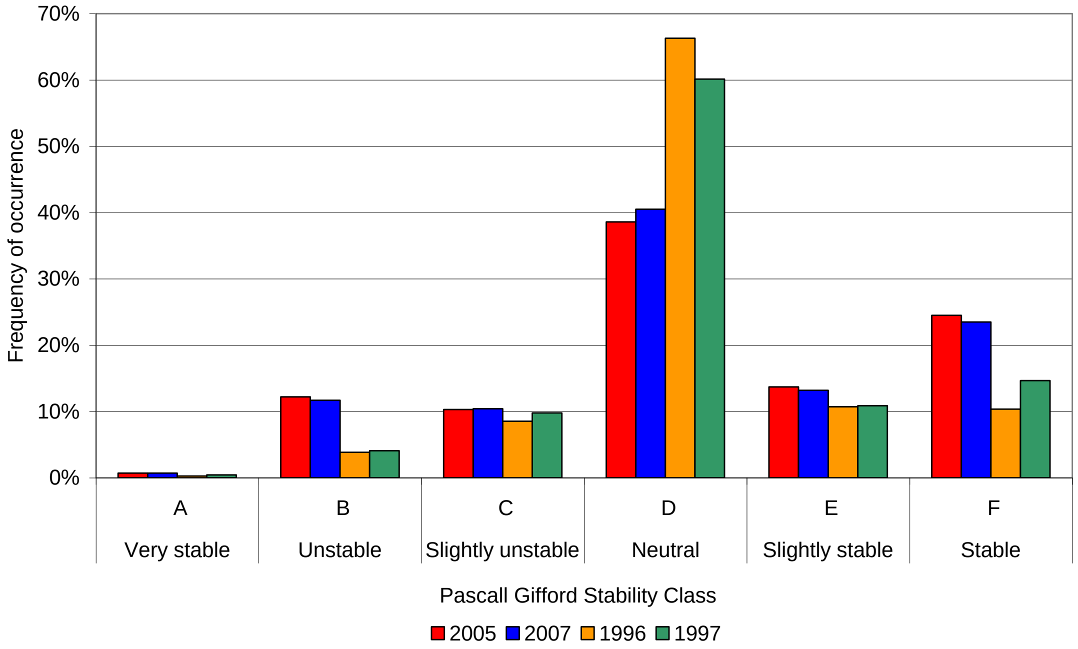
AUSPLUME 1996 dataset.

Stability Class	Definition	Stability class	Minimum mixing height (m)	Maximum mixing height (m)	Minimum wind speed (m/s)	Maximum wind speed (m/s)
A	Very stable	0.3%	394	2075	0.3	2.8
B	Unstable	3.8%	121	2186	0.2	4.9
C	Slightly unstable	8.5%	64	2375	0.2	14.7
D	Neutral	66.3%	50	2886	0.1	14.8
E	Slightly stable	10.7%	50	254	1.8	5.4
F	Stable	10.4%	50	72	0.1	3.3

Table C.4
AUSPLUME 1997 dataset.

Stability Class	Definition	Stability class	Minimum mixing height (m)	Maximum mixing height (m)	Minimum wind speed (m/s)	Maximum wind speed (m/s)
A	Very stable	0.4%	396	1642	0.3	2.7
B	Unstable	4.1%	121	1559	0.1	4.8
C	Slightly unstable	9.8%	96	1721	0.0	11.7
D	Neutral	60.1%	50	1519	0.2	14.2
E	Slightly stable	10.9%	50	236	1.8	5.4
F	Stable	14.7%	50	109	0.0	3.3

Figure C.1
Frequency of occurrence of stability class categories for each meteorological year.



C.3 Scenario testing

To examine how dispersion modelling results may differ between the new and previous AUSPLUME datasets, four simple emission scenarios have been tested. The emission sources considered were a short stack, a taller stack, and low-level area and volume sources. The parameters for each example are given in Table C.5. These cases were selected to provide a range of basic discharge scenarios.

Table C.5

Emission scenarios.

Scenario ID	Scenario name	Scenario description
R1	Small stack source	10 m stack, efflux velocity 15 m/s, stack diameter 0.3 m, exit temperature 100°C, unit emission rate
R2	Large stack source	20 m stack, efflux velocity 15 m/s, stack diameter 0.8 m, exit temperature 200°C, unit emission rate
R3	Area source	Area source, 5 m x 10 m, unit emission rate
R4	Volume source	Volume source, 5 m x 10 m x 3 m, unit emission rate

The following sections present the results for each of the emission scenarios listed in Table C.5, for the four years of data. Comment is provided about the types of meteorological parameters (stability class, mixing height and wind speed) that give rise to the highest concentrations for the 1996 and the 2005 datasets. For each scenario, three graphs are also presented. These graphs depict the high-end concentrations, for different averaging periods and concentration percentiles. For each measure of concentration, the values over the model grid points have been sorted and the highest 200 plotted in the ranked order. The model domain is a grid of 50 m cells centred on the source.

C.3.1 Scenario R1 – small stack source

For scenario R1, the three graphs are presented in Figure C.2. These show the maximum 1-hour average, the 99.9th percentile 1-hour average and the maximum 24-hour average concentrations for each year. Generally, the 99.9th percentile 1-hour average and the maximum 24-hour average show little variation between the different years.

Regarding the maximum 1-hour average concentrations, the 2005 and 2007 datasets are close to each another, so are the 1996 and 1997 datasets. However, the 2005 and 2007 datasets give generally lower concentrations. An examination of the meteorological parameters giving rise to maximum 1-hour concentrations indicates the following for 1996 and 2005:

- The high end of the concentration range obtained using the 2005 data is dominated by stability classes B and C, with mixing heights several hundred metres and wind speeds around 2-3 m/s. This suggests that peak concentrations occur under plume fumigation or coning conditions.

- Results using the 1996 data are dominated by stability class D, mixing height 50 m and wind speed 0.5 m/s for the highest concentrations, followed by stability class C (with mixing heights of several hundred metres and wind speeds of down to less than 2 m/s). Neither of these combinations occurs in the 2005 data, as the minimum mixing height for class D is 100 m, and class C does not have wind speeds below 2 m/s.

Differences occurring between the datasets in the maximum 1-hour concentrations are largely removed when considering the 99.9th percentile. The modelling GPG (MfE, 2004b) recommends examination of the modelled upper percentiles as representatives of the maximum hourly concentrations, and the 99.9th percentile 1-hour modelled concentration is often used for this purpose. At this percentile level, the concentrations arise under similar meteorological conditions in each dataset. The cases of unrealistically conservative combination of stability class D and mixing height 50 m in the 1996 and 1997 datasets appear only at higher percentile levels.

C.3.2 Scenario R2 – large stack source

For the large stack source scenario, the situation is similar to that presented for the small stack scenario, i.e. the 99.9th percentile 1-hour average and maximum 24-hour average concentration results are similar between all years. There remain differences between the previous and new datasets for the maximum 1 hour average concentrations (see Figure C.3). As for scenario R1, the previous datasets produce higher concentrations for scenario R2.

An examination of the meteorological parameters giving rise to maximum 1-hour concentrations indicates the following:

- The high end of the concentrations obtained using the 2005 meteorology is dominated by stability classes B and A (unstable or very unstable). Mixing heights are of the order 1,000 m and wind speeds between 2 m/s and 4 m/s. This suggests that peak concentrations occur under plume looping conditions, which could be typical of an unstable atmosphere.
- Using the 1996 meteorological data, peak concentrations are dominated largely by stability class D, with mixing heights of 50 m and wind speeds of 3 - 4 m/s, then classes A and B, similar to the 2005 results.

In this scenario, the low mixing heights in the 1996 data under neutral conditions have lead to higher GLCs than when using the 2005 data. Aside from these cases, for the higher stack with higher exit temperature, the greatest impacts occur under more unstable conditions. For the same reasons as scenario R1, differences between results from the different datasets are reduced when examining the 99.9th percentile or 24-hour-average GLCs.

C.3.3 Scenario R3 – area source

The maximum 1-hour-average concentrations are similar for all meteorological datasets. Being a low-level source, the maximum impacts occur under stable conditions. For each meteorological dataset the highest concentrations occur mainly under stability class F, with mixing height 50 m and wind speed 0.5 m/s. A few differences can be seen in Figure C.4, where the top 10 highest impacted receptors have a higher GLC arising from the 1996 dataset. Some of these occur under stability class C and wind speed 0.5 m/s, which do not occur in combinations in the new datasets.

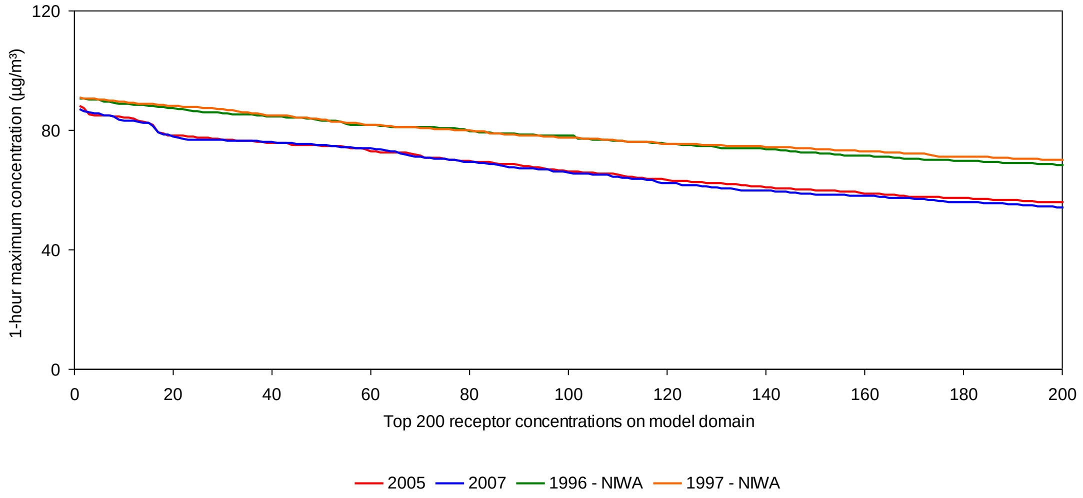
At the 99.9th percentile level and for 24-hour averages, GLCs arising from the 2005 and 2007 datasets are higher than from the 1996 and 1997 datasets. The new datasets have a larger proportion of stable conditions (classes E and F) than the previous datasets, under which the highest impacts occur for low-level sources.

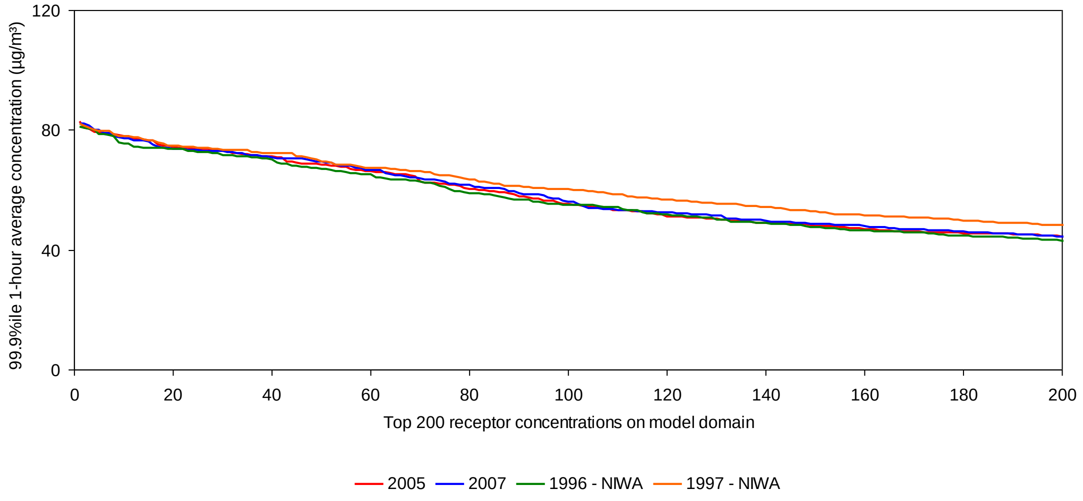
C.3.4 Scenario R4 – volume source

The relative sizes of the GLCs arising from the alternative meteorological datasets are similar in scenario R4 to scenario R3. This is to be expected for the low-level source. The maximum 1-hour average GLCs occur under stable conditions for each meteorological dataset. These are stability class F, mixing height 50 m and wind speed 0.5 m/s. For the 99.9th percentile and 24-hour averages, the new meteorological datasets lead to higher concentrations, due to their more frequent stable conditions (see Figure C.5).

Figure C.2

Small stack source scenario R1.





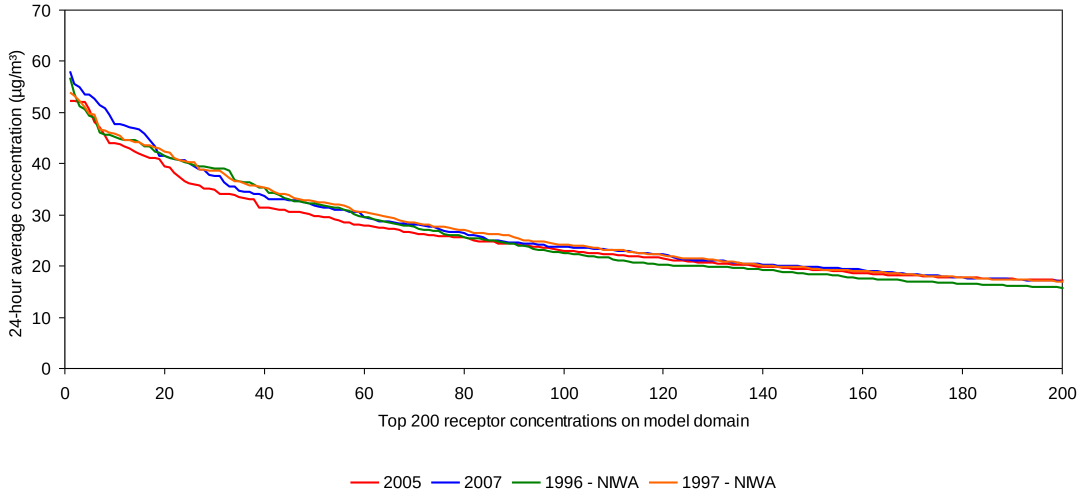
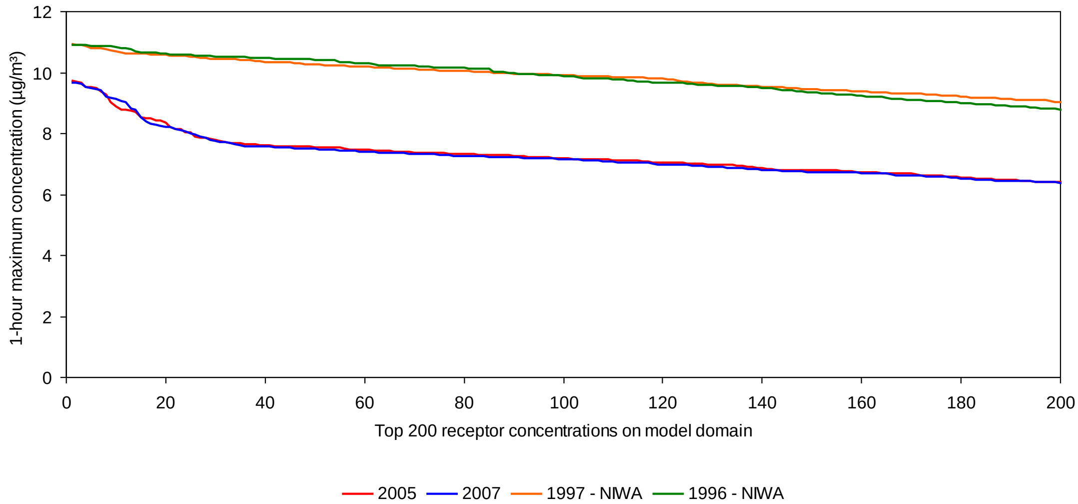
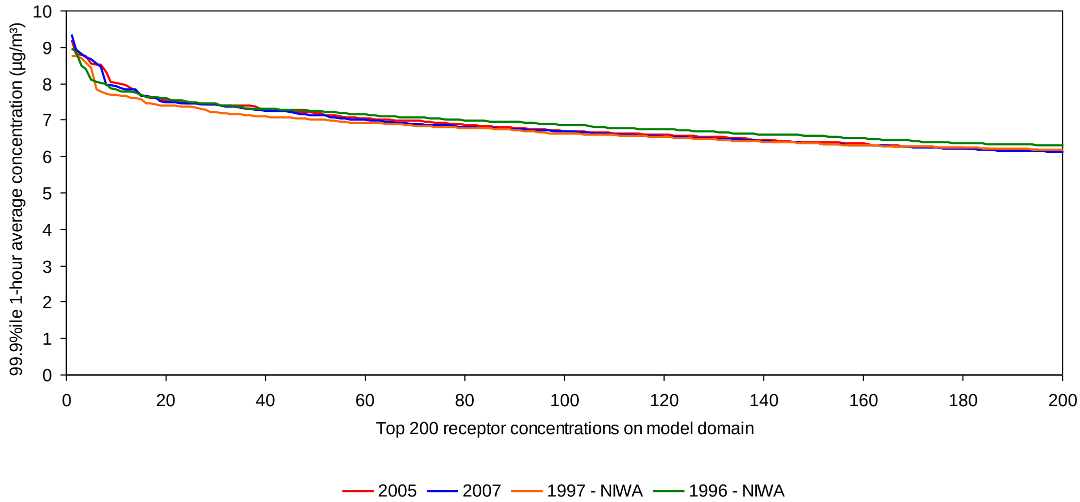


Figure C.3

Large stack source scenario R2.





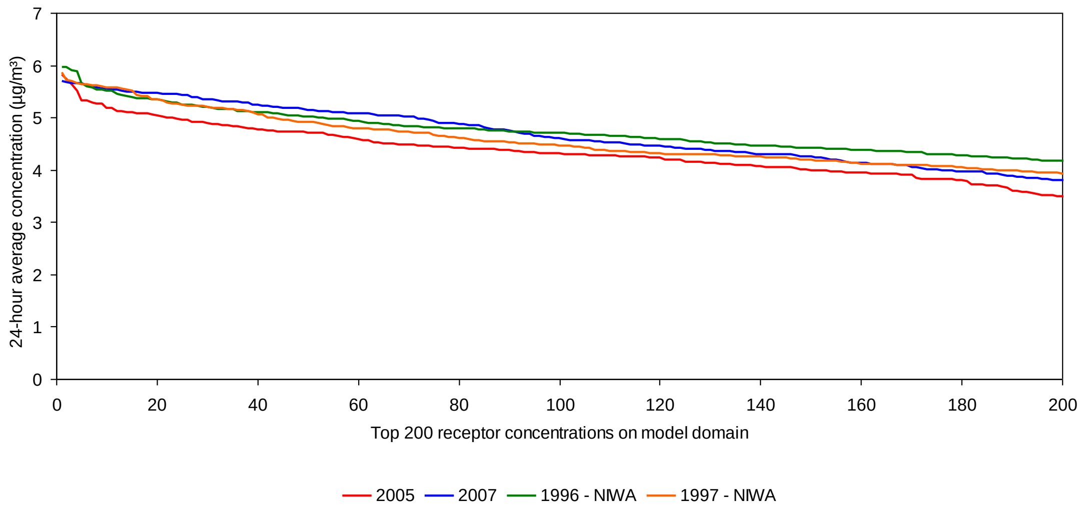
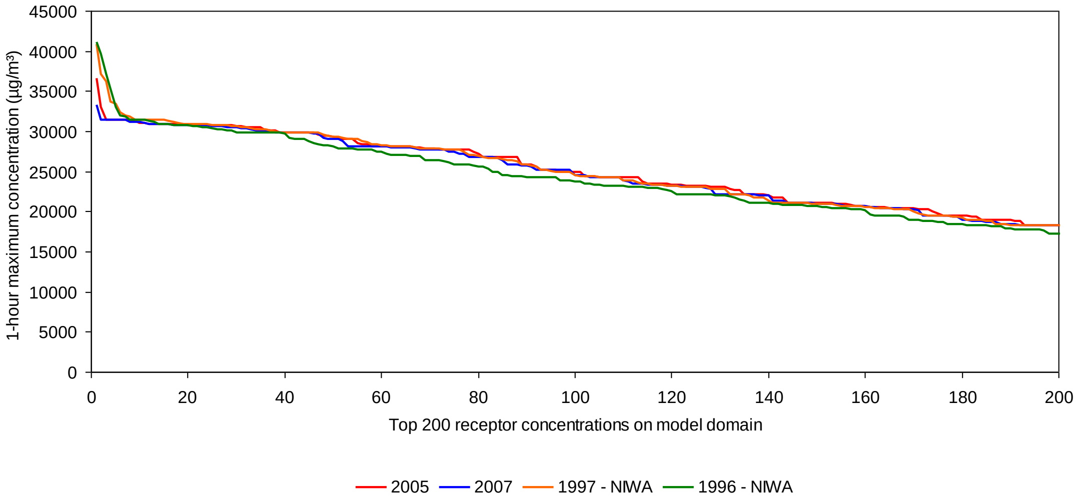
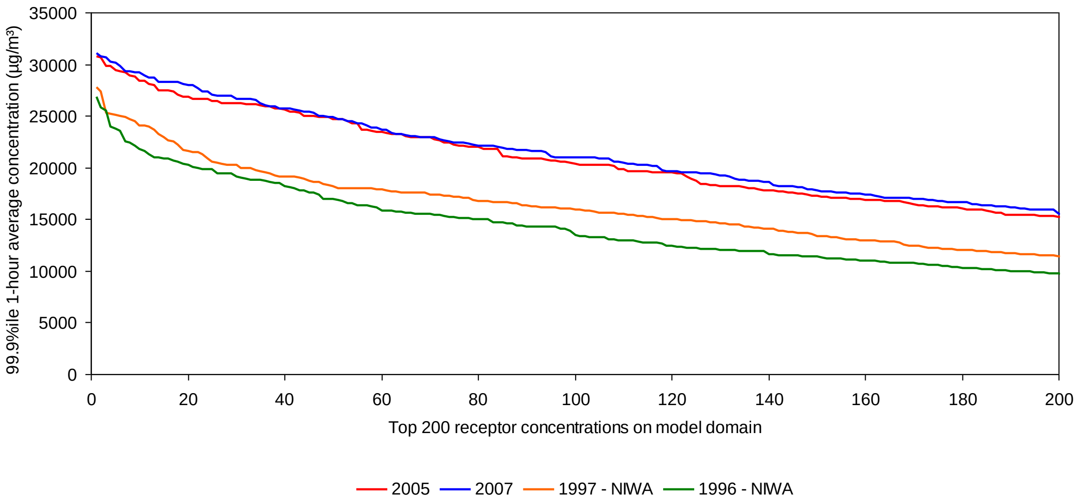


Figure C.4

Area source scenario R3.





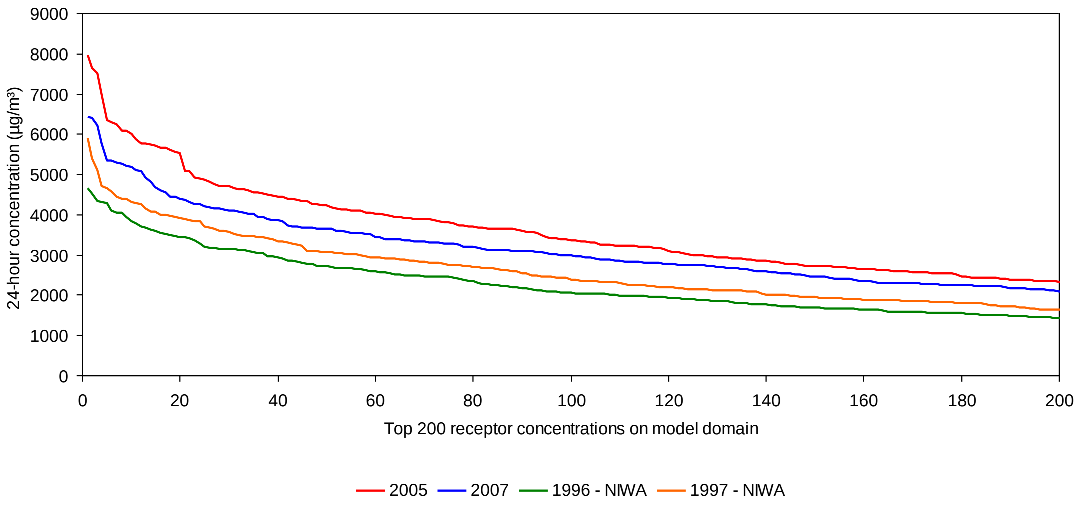
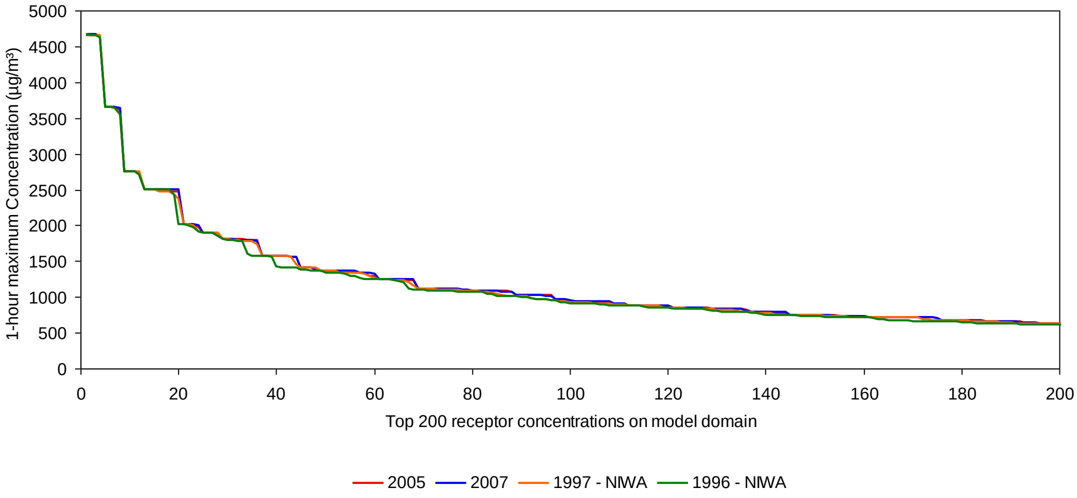
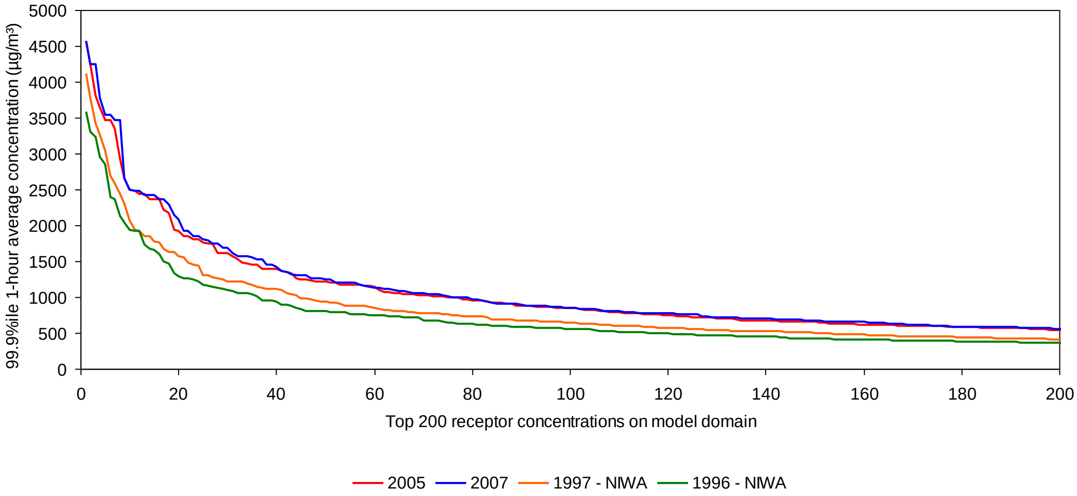
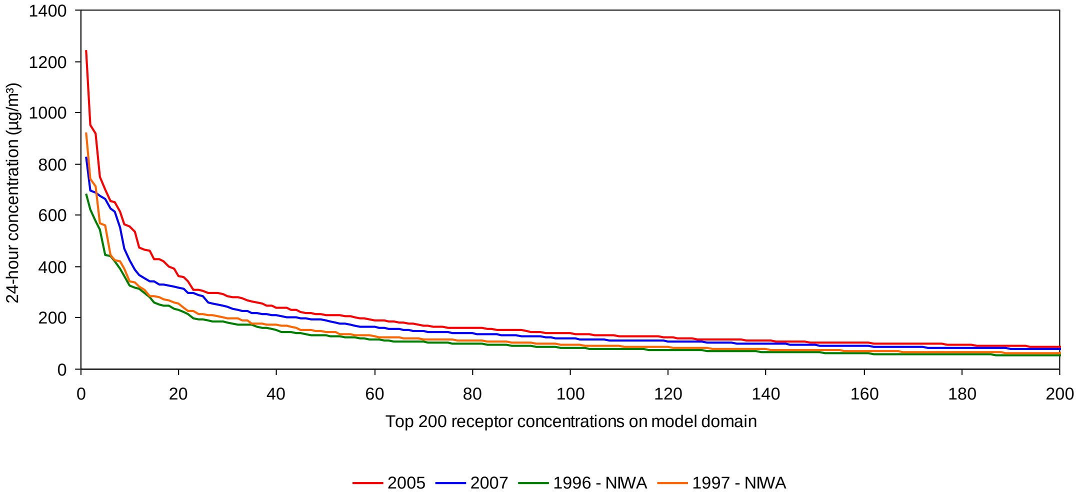


Figure C.5

Volume source scenario R4.







C.4 Summary

An examination of the derived meteorological parameters associated with the 1996, 1997, 2005 and 2007 datasets has shown that the 1996 and 1997 datasets have a different distribution of stability classes to the 2005 and 2007 datasets. Although the provenance of the 1996 and 1997 datasets is unclear, it seems unlikely that the same methods were used for those datasets and the 2005 and 2007 datasets.

There are some differences in model predictions between the 1996/1997 and 2005/2007 for the four discharge scenarios. This has been attributed to some combinations of meteorological parameters in the previous datasets, but not in the new datasets; and to the higher frequency of stable conditions in the new datasets.

For stack sources the unrealistic combination of stability class D, mixing height 50 m and wind speed of 0.5 m/s in the previous datasets has contributed to higher maximum hourly concentrations than those from the new datasets. However, the 99th percentile hourly and maximum 24-hourly GLCs are similar for the 1996/1997 and 2005/2007 datasets. For low-level sources the higher frequency of occurrence of stable conditions in the new datasets has increased the 99th percentile hourly and maximum 24-hourly GLCs. However, the maximum hourly concentrations for low-level sources are similar for the 1996/1997 and 2005/2007 datasets.

Appendix D: CALMET parameters - regional domain

The following tables list the parameters used in the regional-scale CALMET runs. These are referred to as the Surface-Data and Blended-Profile runs, as described in Appendix A. Tables D.1 and D.2 contain parameters applicable to both runs (run control, map projection and grid control parameters). Wind field options and site locations for the Surface-Data run are listed in Tables D.3, D.4 and D.5 contain; and those for the Blended-Profile run in Tables D.6, D.7 and D.8.

The upper-air parameters for the Surface-Data run are listed in Table D.5. Input data at these sites are profiles extracted from the TAPM runs, including those to be blended with surface observations, and profiles from extra locations around the edge of the CBD and over sea points. The profiles to be blended with surface observations are offset from the surface sites, 2 km to the east, to allow the similarity profiles to be extrapolated directly over the surface sites without influence on the wind field from the TAPM profiles (this is accounted for in the blending process).

The upper-air sites for the Profile-Data run, listed in Table D.8, include the blended profiles. All upper-air sites in this run are at locations coincident with the surface sites in Table D.7.

Table D.1

Run control and map projection. The TTM projection option is selected, which allows any rectangular coordinate system to be used (Surface-Data and Blended-Profile runs).

Parameter	Value
Time period	1 January to 31 December, 2005 and 2007
Time zone	UTC+1200
Time step	3600 s
Map projection	Tangential Transverse Mercator (TTM)
Datum region	WGS-84
Projection origin	36.6910°S, 174.7350°E
False origin (NZTM coordinates)	(1755000, 5938000) (m)

Table D.2

Grid control (Surface-Data and Blended-Profile runs).

Parameter	Value
SW corner of grid cell (1,1)	(1702, 5870) km
Grid dimensions	105 x 135 grid cells at spacing 1.0 km
Vertical grid, number of layers	12
Cell-face heights for vertical grid (m)	0, 20, 50, 90, 130, 200, 300, 450, 650, 950, 1400, 2000, 3000

Table D.3

Wind field options (Surface-Data run).

Parameter	Value
Extrapolation of surface wind observations (IEXTRP)	-4; MOST used; layer 1 data at upper air stations ignored
Layer-dependent biases (BIAS)	-1, 11x0
Vertical extrapolation of surface winds (RMIN2)	-1.0; extrapolate all surface stations
Maximum radius of influence of met data	RMAX1 = RMAX2 = 3 km; RMAX3 = 100 km
Relative weighting of first-guess field and observations	R1 = R2 = 1.5 km
Radius of influence of terrain features	TERRAD = 10 km

Table D.4

Surface meteorological stations - observations from these sites are used in both CALMET runs (Surface-Data run, time zone = -12).

Name	Source	X (km, NZTM)	Y (km, NZTM)	Anem. Ht. (m)
Khyber Pass*	ARC	1757.826	5918.507	12.8
Musick Point*	ARC	1769.523	5920.383	17
Penrose	ARC	1761.751	5914.176	6
Pukekohe	ARC	1765.441	5880.820	10
Takapuna	ARC	1756.059	5928.077	10
Henderson	ARC	1745.468	5919.216	10
Onehunga	ARC	1760.436	5911.538	10
Wiri	ARC	1766.415	5904.322	10
Mangere	CliDB	1758.089	5907.905	10
Warkworth	CliDB	1749.466	5966.780	10
Leigh	CliDB	1761.325	5984.504	10
Airport	CliDB	1759.164	5902.929	10
Owairaka	CliDB	1753.773	5915.796	10

* Mast height is above the roof of the building.

Table D.5

Upper-air meteorological station parameters. These are profiles from TAPM, with numerical identifiers of the form NIIJJ, where N is the grid number and (II, JJ) is the grid-point number (Surface-Data run, time zone = -12).

Identifier	X (km, NZTM)	Y (km, NZTM)
31824	1736.182	5875.391
40563	1733.634	5940.848
41769	1746.303	5946.834
31432	1726.949	5895.270
31047	1716.533	5933.130
31240	1721.982	5914.988
31259	1721.408	5962.779
30554	1702.227	5949.541
30856	1711.423	5956.318
32371	1748.725	5992.888
33056	1765.148	5955.655
32673	1756.962	5997.299
44361	1772.341	5938.775
45043	1778.740	5921.264
33940	1787.878	5915.265
42405	1752.650	5882.795
34439	1801.301	5913.206
42424	1753.307	5902.145
42541	1754.175	5919.336
44722	1776.209	5899.766
43714	1765.743	5891.728
44343	1771.523	5922.383
43538	1763.751	5916.176
43805	1767.441	5882.820
42852	1758.059	5930.077
32461	1751.466	5968.780
32967	1763.325	5986.504
41851	1746.952	5929.076

Table D.6

Wind field options (Blended-Profile run).

Parameter	Value
Extrapolation of surface wind observations (IEXTRP)	-1; No vertical extrapolation is done; layer 1 data at upper air stations ignored
Layer-dependent biases (BIAS)	-1, 11x1
Vertical extrapolation of surface winds (RMIN2)	4.0; no surface stations are extrapolated
Maximum radius of influence of met data	RMAX1 = RMAX2 = 3 km; RMAX3 = 100 km
Relative weighting of first-guess field and observations	R1 = R2 = 1.5 km
Radius of influence of terrain features	TERRAD = 10 km

Table D.7

Surface meteorological stations, including extra surface sites from TAPM (IntX sites are on land, between measurement sites, TapX sites are located on the periphery of the domain, Blended-Profile run, time zone = -12).

Name	ID	Source	X (km, NZTM)	Y (km, NZTM)	Anem. Ht. (m)
Khyber Pass	10001	ARC	1757.826	5918.507	12.8
Musick Point	10002	ARC	1769.523	5920.383	17
Penrose	10003	ARC	1761.751	5914.176	6
Pukekohe	10004	ARC	1765.441	5880.820	10
Takapuna	10005	ARC	1756.059	5928.077	10
Henderson	10006	ARC	1745.468	5919.216	10
Onehunga	10007	ARC	1760.436	5911.538	10
Wiri	10008	ARC	1766.415	5904.322	10
Mangere	10009	CliDB	1758.089	5907.905	10
Warkworth	10010	CliDB	1749.466	5966.780	10
Leigh	10011	CliDB	1761.325	5984.504	10
Airport	10012	CliDB	1759.164	5902.929	10
Owairaka	10013	CliDB	1753.773	5915.796	10
Int1	30012	TAPM	1759.164	5902.929	10
Int2	30013	TAPM	1753.773	5915.796	10
Int3	30021	TAPM	1751.307	5900.145	10
Int4	30022	TAPM	1774.209	5897.766	10
Int5	30023	TAPM	1767.466	5909.126	10
Int6	30024	TAPM	1763.743	5889.728	10
Int7	30025	TAPM	1744.952	5927.076	10
Tap1	20001	TAPM	1736.182	5875.391	10
Tap2	20002	TAPM	1733.634	5940.848	10
Tap3	20003	TAPM	1746.303	5946.834	10
Tap4	20004	TAPM	1726.949	5895.27	10
Tap5	20005	TAPM	1716.533	5933.13	10
Tap6	20006	TAPM	1721.982	5914.988	10
Tap7	20007	TAPM	1721.408	5962.779	10
Tap8	20008	TAPM	1702.227	5949.541	10
Tap9	20009	TAPM	1711.423	5956.318	10
Tap10	20010	TAPM	1748.725	5992.888	10
Tap11	20011	TAPM	1765.148	5955.655	10
Tap12	20012	TAPM	1756.962	5997.299	10

Table D.7 (cont)

Name	ID	Source	X (km, NZTM)	Y (km, NZTM)	Anem. Ht. (m)
Tap13	20013	TAPM	1772.341	5938.775	10
Tap14	20014	TAPM	1778.74	5921.264	10
Tap15	20015	TAPM	1787.878	5915.265	10
Tap16	20016	TAPM	1752.65	5882.795	10
Tap17	20017	TAPM	1801.301	5913.206	10

Table D.8

Upper-air meteorological station parameters. These are profiles from TAPM, with numerical identifiers of the form NIIJJ, where N is the grid number and (II, JJ) is the grid-point number. Profiles referred to as "Blended" have had the TAPM profiles blended with surface observations (Blended-Profile run, time zone = -12).

Name	Source	X (km, NZTM)	Y (km, NZTM)
42941	Blended	1757.826	5918.507
44141	Blended	1769.523	5920.383
43336	Blended	1761.751	5914.176
43603	Blended	1765.441	5880.820
42650	Blended	1756.059	5928.077
41641	Blended	1745.468	5919.216
43134	Blended	1760.436	5911.538
43726	Blended	1766.415	5904.322
42931	Blended	1758.089	5907.905
32360	Blended	1749.466	5966.780
32867	Blended	1761.325	5984.504
43025	Blended	1759.164	5902.929
42538	Blended	1753.773	5915.796
42222	Blended	1751.307	5900.145
44520	Blended	1774.209	5897.766
43831	Blended	1767.466	5909.126
43512	Blended	1763.743	5889.728
41649	Blended	1744.952	5927.076
31824	TAPM	1736.182	5875.391
40563	TAPM	1733.634	5940.848
41769	TAPM	1746.303	5946.834
31432	TAPM	1726.949	5895.270

Table D.8 (cont)

Name	Source	X (km, NZTM)	Y (km, NZTM)
31047	TAPM	1716.533	5933.130
31240	TAPM	1721.982	5914.988
31259	TAPM	1721.408	5962.779
30554	TAPM	1702.227	5949.541
30856	TAPM	1711.423	5956.318
32371	TAPM	1748.725	5992.888
43678	TAPM	1765.148	5955.655
32673	TAPM	1756.962	5997.299
44361	TAPM	1772.341	5938.775
45043	TAPM	1778.740	5921.264
33940	TAPM	1787.878	5915.265
42405	TAPM	1752.650	5882.795
34439	TAPM	1801.301	5913.206