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Vehicle Emissions and Air Quality

Ozone Levels in Auckland and Canterbury

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Executive Summary

A survey has been conducted of ozone levels around Auckland using a mobile sensor attached to a light aircraft. Measurements were made on selected days during the summer of 1997 in order to:-

- a) Determine the horizontal structure of ozone over the city
- b) Determine the vertical structure of ozone over the city
- c) Look for high concentrations of ozone due to pollution from the city

The experimental days were selected on the basis of significant potential for ozone formation - that is sunny, warm days with light winds. Data from the existing ground based network of ozone sensors was also used.

A supplementary measurement programme was also undertaken using ground based sensors in Christchurch.

The measurement phase was not as extensive as had been anticipated, due to firstly the late arrival of the central equipment, and secondly the relatively few suitable days during February and March 1997.

Despite this, some very interesting results were obtained.

No seriously elevated ozone concentrations were found during the surveys. This confirms the results of ground based monitoring, which shows that although high ozone concentrations do occur in Auckland, they are relatively infrequent. This aircraft survey shows that the spatial structure of ozone is probably not as complex as that around overseas cities studied in the same way.

This is good news for Auckland. Although elevated ozone concentrations do occur, they may not be as serious as they potentially could be.

The Christchurch work, although not yet fully analysed, as shown more defined structure. Elevated values of ozone were observed, at places and times that were consistent with ozone formation in the plume from the city on warm sunny days. Although levels did not exceed guidelines, they were certainly in excess of normal background levels.

This is not so good for Christchurch. Previously thought a city free from ozone issues, this survey shows that further monitoring in summer may be prudent.

The monitoring in Auckland will continue next summer, and in Christchurch subject to funding.

Overall, the study has shown:-

1. Slightly elevated levels of ozone pollution can be found in the 'plume' of emissions from Auckland city.
2. During the summer of 1996/97, ozone levels around Auckland were well below guideline levels, and would not cause any significant problems. However the longer term ground-based monitoring showed that this summer generally had lower ozone levels than some previous summers.
3. The horizontal and vertical structure of ozone over Auckland can be explained by the prevailing meteorology and is not as complex as occurs in some other cities.
4. Ozone levels in Christchurch were at times higher than in Auckland, although still below guideline levels.
5. The criteria for assessing potential ozone days may need to be re-assessed, since surface monitoring showed high values on days which were overcast and windy.
6. Further monitoring, both ground-based and elevated, be conducted in Auckland and Christchurch next summer.

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1. Introduction

Meteorological and emission characteristics within the Auckland region (and other regions), have previously been identified as conducive to the formation of photochemical oxidants such as ozone (O₃) (Bell & Fisher, 1995; McKendry, & Fisher, 1996). Because photochemical oxidants have considerable environmental and health impacts, an understanding of the processes which transform and transport such pollutants is an important area of research.

1.1 Auckland

At present two fixed ozone monitoring stations are located within the Auckland region (at Pukekohe and Musick Point). In order to augment the air quality data obtained from these sites and gain a more complete understanding of the chemical and physical mechanisms associated with the formation of photochemical contaminants, the National Institute of Water and Atmospheric Research (NIWA) was contracted to undertake a preliminary survey of ozone concentrations utilising a light aircraft sampling technique.

The aim of the study was to examine the horizontal and vertical distribution of ozone within Auckland's urban emission plume during meteorological conditions associated with a high photochemical event potential. Therefore the field programme operated between the summer months of February and March 1997 when a high potential for elevated ozone concentrations traditionally exists (McKendry & Fisher, 1996).

A preliminary analysis of the aircraft survey and associated data obtained from surface based meteorological stations and ozone monitoring sites is detailed within this report. However it is first necessary to examine background information regarding basic chemical relationships within urban emission plumes and the methodologies employed within this aircraft survey.

1.2 Canterbury

As an extension to the study, a brief survey was also undertaken in Canterbury. This was conducted around Christchurch, using a fixed monitoring location at Lincoln, and a mobile monitor in a vehicle. The work was conducted as part of an MSc Thesis.

2. Background Information

2.1 Causes

Within urban airsheds ozone is principally produced by a complex series of photochemical transformations. These reactions involve the oxidation of volatile organic compounds (VOC's) and nitrogen oxides (NO_x) in the presence of strong sunlight (Bell & Fisher, 1995; McKendry & Fisher, 1996). Under certain meteorological circumstances these pre-cursor chemical species can contribute to the formation and accumulation of high levels of ozone (and other secondary pollutants).

2.1.1 Auckland

The main sources of the pre-cursor pollutants have been identified as emissions from industrial parks and motor vehicles. In Auckland, these are principally located on the narrow Auckland isthmus (see Figure 2.1). This region is characterised by high population densities, several large industrial estates, and high traffic volumes (Auckland Regional Council, 1995; Statistics NZ, 1995). In fact air quality studies indicate that the levels of pre-cursor emissions are high enough for photochemical pollution to occur every day (Wratt *et al*, 1992 cited by Bell & Fisher, 1995).

Figure 2.1 : The Auckland region (100 m contour lines). (Source: Bell & Fisher, 1995).

It is therefore recognised that the frequency and extent to which photochemical pollutants accumulate within Auckland is strongly dependent upon the prevailing meteorology and season. For example light winds, strong solar radiation, and warm temperatures have been identified as conducive to the formation of photochemical oxidants within the Auckland region. These periods are often associated with anti-cyclonic conditions (during the summer months) when large scale pressure gradients are weak and sea breezes tend to dominate local wind patterns. In such instances pollutant dispersal is restricted and photochemical activity is high.

Meteorological conditions associated with a high probability for producing elevated levels of ozone occur approximately 3 days per year (Bell & Fisher, 1995; Brasell, 1982; McKendry, 1989; McKendry & Fisher, 1996; Wratt *et al*, 1988). However the time required to produce ozone through photochemical reactions may mean that maximum concentrations occur tens of kilometres from the sources of the nitrogen oxide and hydrocarbon precursors. Therefore, the interaction of transportation, emission, and transformation processes often results in considerable spatial and temporal variation between photochemical pollutant concentrations (Bell & Fisher, 1995; Karl, 1980; Varey *et al*, 1988).

Numerous studies have examined the variation in ozone and primary pollutant surface level concentrations within urban emission plumes (Brasell, 1982; Karl, 1980; Leahey & Hansen, 1990). Within urban areas, ambient conditions are generally characterised by depleted ozone levels. These occur when nitric oxide (NO) emissions scavenge available ambient ozone concentrations. However, with increasing downwind distances from nitrogen oxide sources, ozone concentrations are found to gradually rise and often exceed levels up-wind of the city. Such recovery (and net formation) rates are highly dependent upon nitrogen oxide temporal emission patterns and meteorological conditions (Brasell, 1982; Karl, 1980; Leahey & Hansen, 1990).

2.1.2 Canterbury

The impact of urban emissions upon ambient ozone concentrations downwind of a city can be observed in variations within diurnal pollutant concentrations recorded at the Lincoln ozone monitoring site. A mobile air quality station was located about 15 km south west of Christchurch City, at Lincoln. On the 12th February when the monitoring site was positioned outside of the city's urban plume, relatively constant, low, background ozone concentrations were observed (see Figure 2.2), of the order of 5-12 ppb.

In contrast, the diurnal pollutant pattern obtained from the 13th February, when the site was located downwind of the city, shows a distinct ozone peak in the middle of the afternoon. The peak reached 30 ppb, or $60 \mu\text{g m}^{-3}$. This is likely to be attributable to the formation of ozone within the emission plume (see Figure 2.2), and represents a reasonably significant measurement for this region.

Several other measurements in the Canterbury region (not shown here) were elevated, indicating that ozone formation does occur around Christchurch. Further, longer term monitoring will be required to indicate if this is likely to be an issue in the Canterbury region.

2.1.3 Summary

The use of light aircraft has been found to be an effective method for obtaining a more detailed understanding of the vertical and horizontal distribution of ozone within the atmosphere. In particular, data obtained from aircraft surveys has proven useful in circumstances when the surface monitoring network was either sparse or potentially misrepresentative of the spatial distribution of ozone within a region (Clarke & Ching, 1983; McElroy & Smith, 1993; McKendry *et al*, 1996).

Therefore the use of aircraft sampling techniques to survey ozone concentrations and formation mechanisms is particularly relevant within the Auckland region where it is impractical to establish surface monitoring stations within the large bodies of water surrounding the city. The location of the city also means that convergent sea breezes (originating on either side of the Auckland isthmus) may induce complex air flow (and hence pollutant dispersion) patterns (McKendry, 1989).

It has been postulated that in suitable circumstances the pollutants formed during sea breezes may become trapped in a stable layer overnight and then vertically transfer to ground level during the morning (Bell and Fisher, 1995). Aircraft ozone sampling is therefore the optimum method suitable for examining this mechanism.

Figure 2.2: Lincoln site diurnal ozone concentrations for the 12th February (top) and 13th February.
(1 ppb = 2 $\mu\text{g m}^{-3}$)

2.2 Effects

The accumulation of the ozone within the ambient air has aesthetic (photochemical smog), environmental (corrosive to vegetable material), and community health impacts. For example ozone is a highly oxidising compound. The effects of short term exposures include the impairment of pulmonary functions, increased frequency in asthmatic attacks, and eye irritations (Ministry for the Environment, 1994; Swedish Government Committee on Automotive Air Pollution, 1983).

Ozone is generally regarded as one of the most insidious air pollutants, and has been identified as a high priority issue for many Northern hemisphere industrialised countries.

2.3 Guidelines

The most common way to assess ozone effects is to monitor the concentrations and compare these to well established international guideline levels.

Guidelines adopted by the New Zealand Ministry for the Environment (1994) regarding maximum allowable ambient air pollutant concentrations are presented in Table 2.1. These exposure levels are based on the Health Department's former guidelines which aim to prevent adverse chemical effects to human health (WHO, 1987). The reference method specified by the Ministry for the Environment (1994) for measuring O₃ concentrations is by chemiluminescence or ultraviolet absorption (based on the method AS 2524-1982).

Averaging Period	Concentration ($\mu\text{g}/\text{m}^3$)	Concentration (ppb at 0°)
1 Hour	150	77
8 Hours	100	51

Table 2.1: Ozone ambient air guidelines (Ministry for the Environment, 1994).

3. Methodology

3.1 Experiment Design

For the duration of the monitoring programme a twin engine, four seated Piper Apache light aircraft was utilised. All of the sampling flights were initiated and terminated from the Royal New Zealand Air Force base located at the Whenuapai aerodrome (where the aircraft was periodically based). Instrumentation installed within the aircraft measured the chemical and physical variables of ozone concentration, position, altitude, and ambient temperature. The operation of the equipment and record keeping required two researchers in addition to the services of the pilot.

Monitoring flights occurred between the 14th February and 27th March. Earlier commencement of the study was inhibited due to delays involving the configuration of the ozonesonde by the manufacturer (the field monitoring programme was active from the 10th February). The days selected for sampling occurred when the morning meteorological conditions fully or partially satisfied the criteria of relatively low wind speeds, little or no cloud cover, and high to moderate temperatures.

These days were judged as those most conducive to ozone formation, and included all but one of worst case days during the experiment period. They are thought to be representative of the days for ozone formation over Auckland during the whole 1996/97 summer period - ie no obviously more severe days were missed, even earlier in the summer.

To examine the formation of ozone within Auckland city's urban emission plume aircraft sampling paths were principally determined by the predominant wind directions — the majority of the surveying occurring downwind of central Auckland city. However, to gain an understanding of background ozone levels, monitoring periods were usually initiated upwind of primary pollutant sources located on the Auckland isthmus. Vertical ozone profiles were obtained via slow spiralling of the aircraft. Such aircraft spirals were usually between 2 - 3 kilometres in diameter.

3.2 Equipment

Ozone concentrations were measured using the Gesellschaft Fur Angewandte Systemtechnik (GFAS) OS-B-2 ozonesonde. The OS-B-2 ozonesonde offered the advantages of a accurate ($\pm 5\%$), lightweight, comparatively inexpensive, robust, rapid response time (1 second) instrument which could be installed without requiring extensive modifications to the aircraft or monitor (see Appendix A for the ozonesonde specifications).

The instrument measures the concentration of ozone based on a surface chemiluminescence method. During operation, air flows over a replaceable chemiluminescence target, where ozone molecules within the ambient air react with an organic dye incorporated on to the cover surface of the target. The intensity of the chemiluminescence reaction between the organic dye and ozone is proportional to the ozone concentration and is converted by a photomultiplier into an analogue signal (0 - 2 volts).

The monitor and battery power supply were installed in the aircraft luggage compartment located behind the rear passenger seats. Air was funnelled to the ozonesonde via a half inch diameter teflon intake tube which extended through the nose of the aircraft. The intake tubing was located far enough away from the aircraft exhausts to avoid contamination of the sampled air. To ensure that flow rates to the instrument were sufficient but not excessive, the tubing was configured in a by-pass mode similar to the arrangement used by McKendry *et al* (1996). This permitted the ozonesonde to bleed off a proportion of air into the aircraft (see Figure 3.1).

The voltage signal from the OS-B-2 ozonesonde was recorded by a Campbell CR10 Data Logger, using a sampling frequency of 1 second and an averaging period of 10 seconds. The data logger was connected to a portable computer which enabled researchers to monitor the real time voltage output from the ozonesonde during monitoring flights and therefore direct ozone search patterns (see Figure 3.1).

Figure 3.1: Ozone monitoring equipment schematics

Prior to the start of a reconnaissance flight the chemiluminescence targets within the ozonesonde are activated by a “pre-ozonisation” procedure. Pre-ozonisation ensures the maximum sensitivity of the instrument. During this procedure the ozonesonde is connected to the supporting GFAS VM-K-2 Control Unit (ozone generator) and exposed to ozone concentrations of approximately 200 ppb for 1 - 1.5 hours.

Once activated, the OS-B-2 is able to be calibrated by recording the output voltage of the ozonesonde unit at a series of known concentrations of ozone generated by VM-K-2 Control Unit and measured by a reference ozone monitor. The linear variation of output voltage to ozone concentration (or calibrated sensitivity, S_{Cal}) can then be calculated from these reference points. For example the 14th February calibration curve is shown in Figure 3.2.

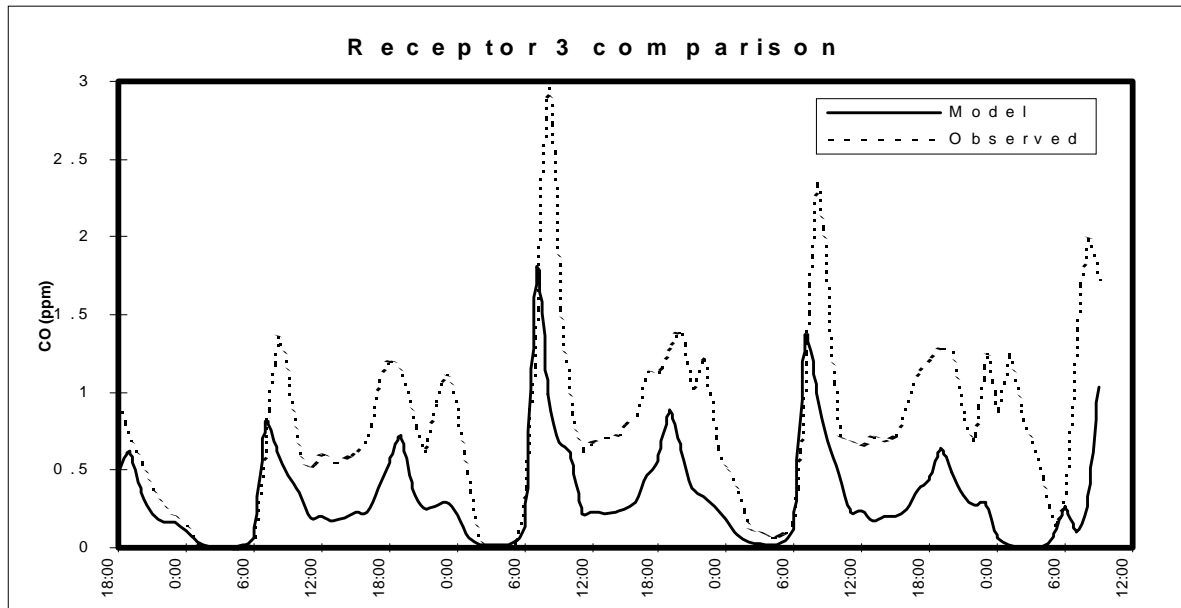


Figure 3.2: The 14th February calibration curve. $S_{\text{cal}} = 8.53 \text{ mV ppb}^{-1}$

The sensitivity of the ozonesonde is also dependent upon temperature, pressure, and relative humidity (GFAS, 1996). Changes in the ambient temperature during sampling periods were accounted for using the relationship defined within the GFAS OS-B-2 manual (1996). However variations in relative humidity and ambient pressure within the boundary layer were estimated by McKendry *et al* (1996) to have a negligible impact upon the OS-B-2 sensitivity and were therefore not focussed upon within this study.

Once activated, the replaceable chemiluminescence targets have an approximate life time of 2,000 ppb hours (McKendry *et al*, 1996). Therefore they were replaced approximately every three survey flights.

Electrochemical ozone sondes have been previously used and validated within other aircraft ozone monitoring programmes (Beekman *et al*, 1995; McKendry *et al*, 1996). McKendry *et al* (1996) generally observed good correlations between ozone concentrations measured by the GFAS OS-B-2 installed within an aircraft and surface reference monitors. This researcher also showed that the slow spiralling of an aircraft provides an accurate method for obtaining fine scale vertical ozone profiles.

Supporting altitude and ambient air temperature readings were taken from the aircraft instrumentation and manually recorded at regular intervals. The geographic coordinates of the aircraft were obtained from a global positioning system (GPS) and directly downloaded into a second portable computer. Both the GPS and portable computer were connected to the battery used to supply power to the ozonesonde and data logger.

4. Results

4.1 Overview

Between the 14th February and the 27th March 1997, a total of four ozone monitoring flights were undertaken within the Auckland region. Survey flights occurred upon the 14th February, 27th February, 28th February, and 27th March with a flying time of 93 minutes. A complete time series of 10 second average ozone concentrations recorded during the monitoring flights is presented in Figures 4.1 and 4.2.

4.2 Data Summary

From these figures it can be observed that on no occasion during the monitoring flights did ozone concentrations exceed either the hourly or 8 hour average O₃ guideline limits (77 ppb and 51 ppb respectively). A general summary of the flight times, average ozone concentrations, and number of vertical ozone concentration profiles completed during the monitoring flights is presented within Table 4.1.

Flight	1	2	3	4
Date	14th February	27th February	28th February	27th march
Time	11:38 - 12:57	12:04 - 14:12	11:21 - 12:19	13:41 - 15:26
Duration (minutes)	79	128	58	105
Number Of Vertical O ₃ Profiles	3	3	0	3
Average O ₃ Concentration (Aircraft)	22.3	18.7	17.5	17.0
Average O ₃ Concentration (Musick Pt)	21.5	18.5	22.7	24.4
Average O ₃ Concentration (Pukekohe)	23.1	21.0	24.7	26.6
Onehunga Automatic Weather Station				
Average Daily Wind Speed (m/s)	2.72	2.97	3.17	1.85
Average Daily Solar Radiation (W/m ²)	193.4	258.3	181.5	181.4
Average Daily Temperature (°C)	19.1	18.3	19.4	16.2
Average Daily Relative Humidity (%)	76.5	78.2	74.5	86.8

Table 4.1: Summary results. (Ozone concentrations are recorded in ppb).

A summary of the average daily meteorological conditions (24 hour average wind speed, temperature, solar radiation, and relative humidity) measured at the Onehunga automatic weather station and the average ozone concentrations measured at Musick Pt and Pukekohe ozone monitoring sites during the aircraft sampling periods are also included within Table 4.1.

Ground level contaminant concentrations were calculated from the 10 minute averages recorded at the two air quality stations during the sampling flights. Oxidant concentrations measured at the Pukekohe station were generally higher than levels measured at Musick Pt. This result is consistent with higher rates of ozone formation occurring at increasing distance from the sources of the primary pollutants (nitrogen oxides and reactive hydrocarbons) — such as those located within central Auckland City.

The ozone survey flight paths for the 14th February, 27th February, 28th February, and 27th March are shown in Figures 4.3, 4.4, 4.5 and 4.6 respectively. However, technical malfunctions during Flight 1 (14th February) resulted in a proportion of the geographic data obtained from a global positioning system (GPS) being lost. Therefore, the approximate flight path of the aircraft during this period is indicated by a the dotted line in Figure 4.3. The position of the initial ozone vertical profile (Spiral 1) has also been estimated from notes made during the reconnaissance flight.

Wind trajectories estimated from hourly wind speed and wind direction data recorded at the Onehunga, North Shore, and Henderson automatic weather stations are also included in Figures 4.3, 4.4, 4.5, and 4.6. Vector lengths were calculated from the product of the average hourly wind speed and time intervals (in this instance 60 minutes).

These diagrams aim to provide a preliminary indication of the primary and secondary pollutant advection pathways during the periods when aircraft ozone monitoring occurred. The calculated trajectories therefore do not account for vertical mixing and variation in wind structure. All trajectory paths are initiated at 7:00 am, and continue to 2pm, to incorporate the high rates of nitrogen oxide and reactive hydrocarbons emitted from morning commuter traffic.

4.3 Detailed Flight Results

The significant events are annotated on Figures 4.1 and 4.2.

14 February

Short flight near to the city, firstly down wind and then up wind, in fairly typical summer conditions with some broken cloud.

Reasonably elevated ozone levels over much of the city, but with very little structure or variation - even upwind. This is indicative of fairly uniform mixing over the region, as confirmed by the vertical profiles. This is due to the light and variable winds, and absence of any well defined 'plume'.

27 February

Major excursion first to the south-west (upwind), and then to the north-east (downwind). Sunny cloud free day, but with moderate winds.

Low, background ozone levels upwind to the south-west, south and south-east of the city. The rapid rise in ozone concentrations encountered in the north of the Hauraki Gulf is almost certainly due to entering the plume from Auckland city. This is also confirmed in the vertical sounding at this time, which shows a strong plume-like feature, and also the highest ozone levels measured, at 800 metres altitude. This plume probably continued right over the Coromandel Peninsula, even growing in extent as photochemical reactions progressed. If this day had been warmer (the average daytime temperature was only 18.3°C, not particularly high for late February), then these peak ozone levels would likely have been considerably higher.

(NB The trajectory data shown in Figure 4.4 is somewhat misleading. The wind trajectories shown are for surface observations, which are often not truly representative of winds higher up. The general weather observations for this day do confirm more of a south-westerly flow, and support the plume argument above.)

28 February

Short flight to the south, but with no profiles. Quite warm and sunny, with light to moderate northerly winds.

Ozone levels were about average background level, consistent throughout the flight, with very little structure or features. However the emissions from the Glenbrook steel mill were visible and the effect of these is seen quite clearly in three dips in the ozone concentration. These are caused by reactive components in the emissions - most likely nitric oxide - destroying ozone.

27 March

Final flight to the south-west (upwind) and north-east (downwind). This day had light but variable winds, was sunny, but not particularly warm, with broken cumulus cloud. It had the highest ozone levels recorded at both of the ground-based stations

Average ozone levels were prevalent over Auckland and the western parts of the Hauraki Gulf. Very low ozone concentrations were found upwind to the south-west, particularly at higher altitudes. This is probably due to a combination of generally lower natural levels later in the season, and an excursion of very clean marine air from the southern oceans.

The concentrations rose above Auckland city, increasing to a maximum near Whangaparaoa Peninsula. The levels fell again in the west of the Hauraki Gulf, moving out of the plume. Levels were generally low everywhere further out in the Gulf, probably because the winds were not sufficient to carry the plume out this far. Higher levels were observed again on return, close the city.

Figure 4.1 Ozone concentrations measured during the airborne monitoring programme. 14th February (left) and 27th February (right).

Figure 4.2 Ozone concentrations measured during the airborne monitoring programme. 28th February (left) and 27th March (right).

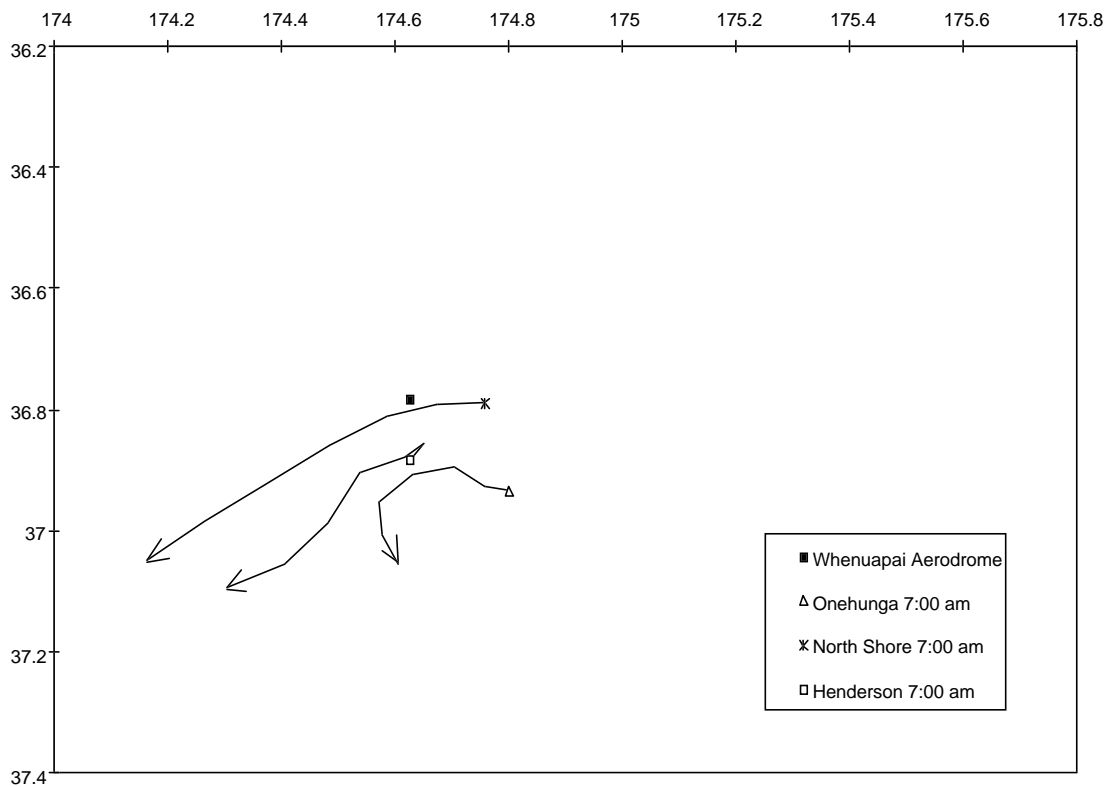
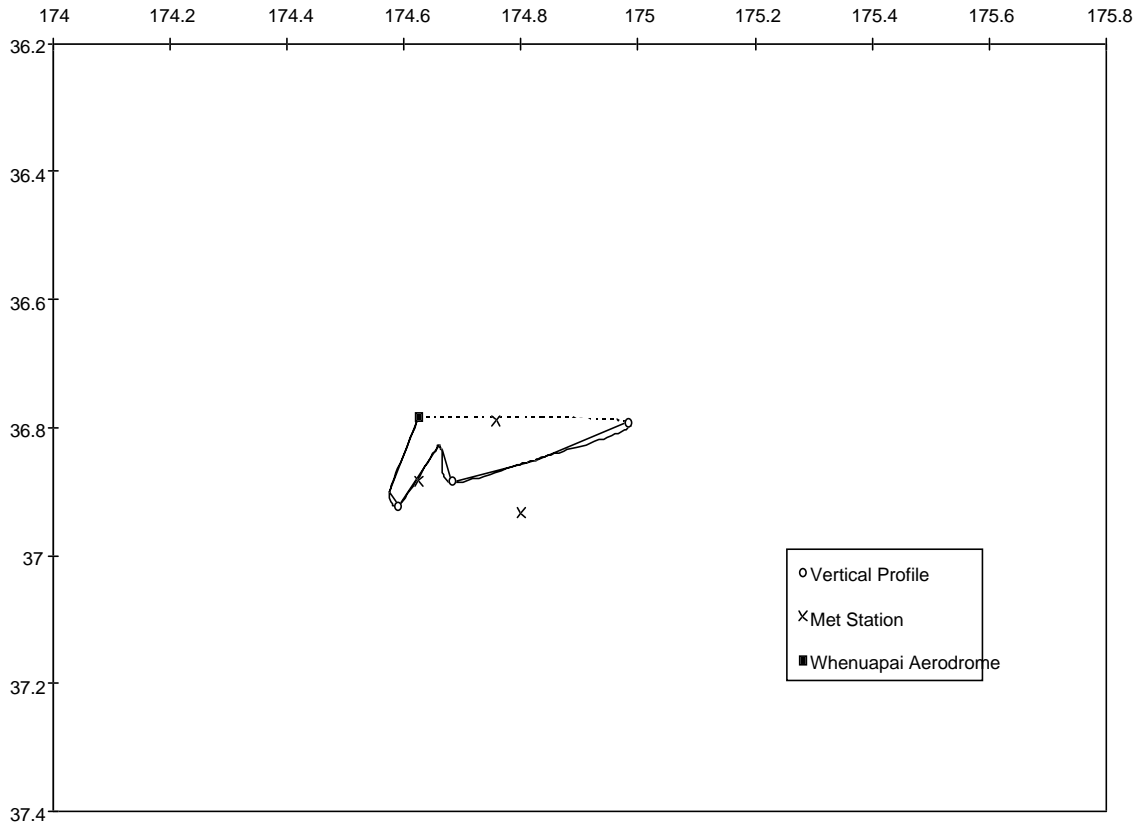


Figure 4.3: The 14th February aircraft survey path (top) and wind trajectories calculated from the Onehunga, North Shore and Henderson meteorological stations. Hourly data (bottom).

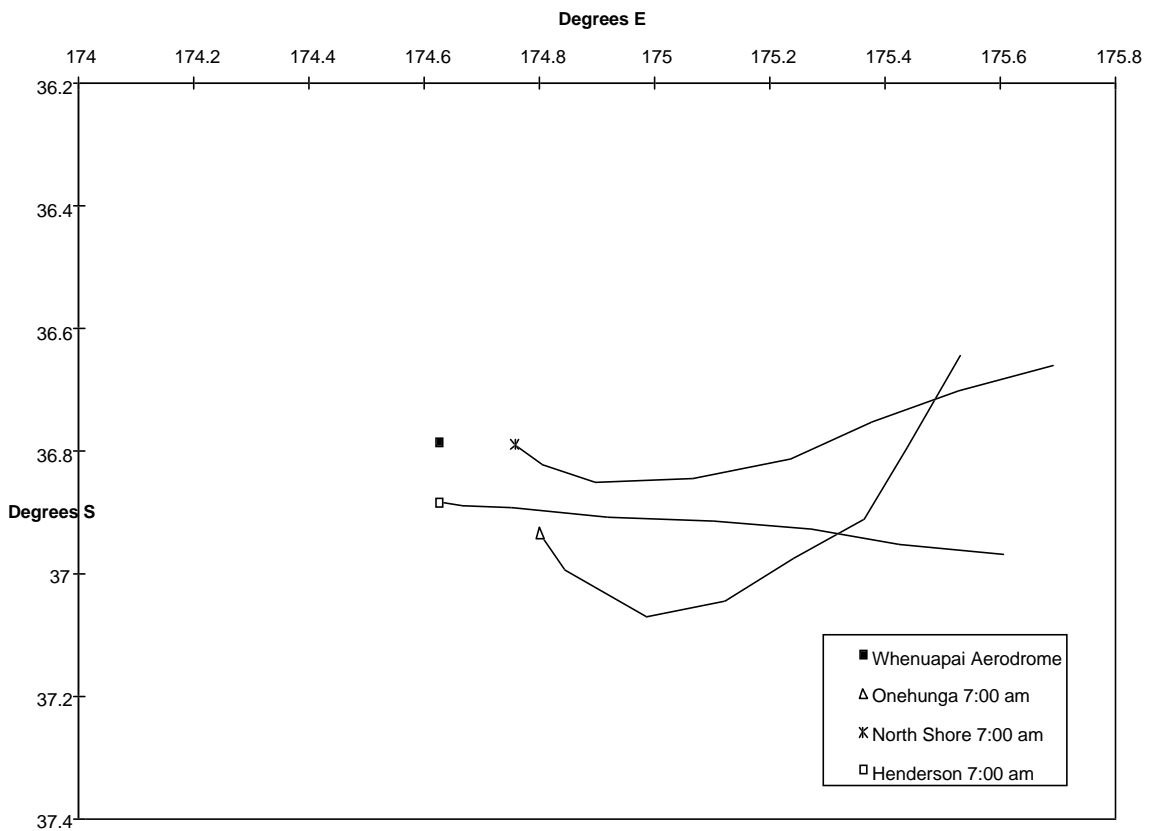
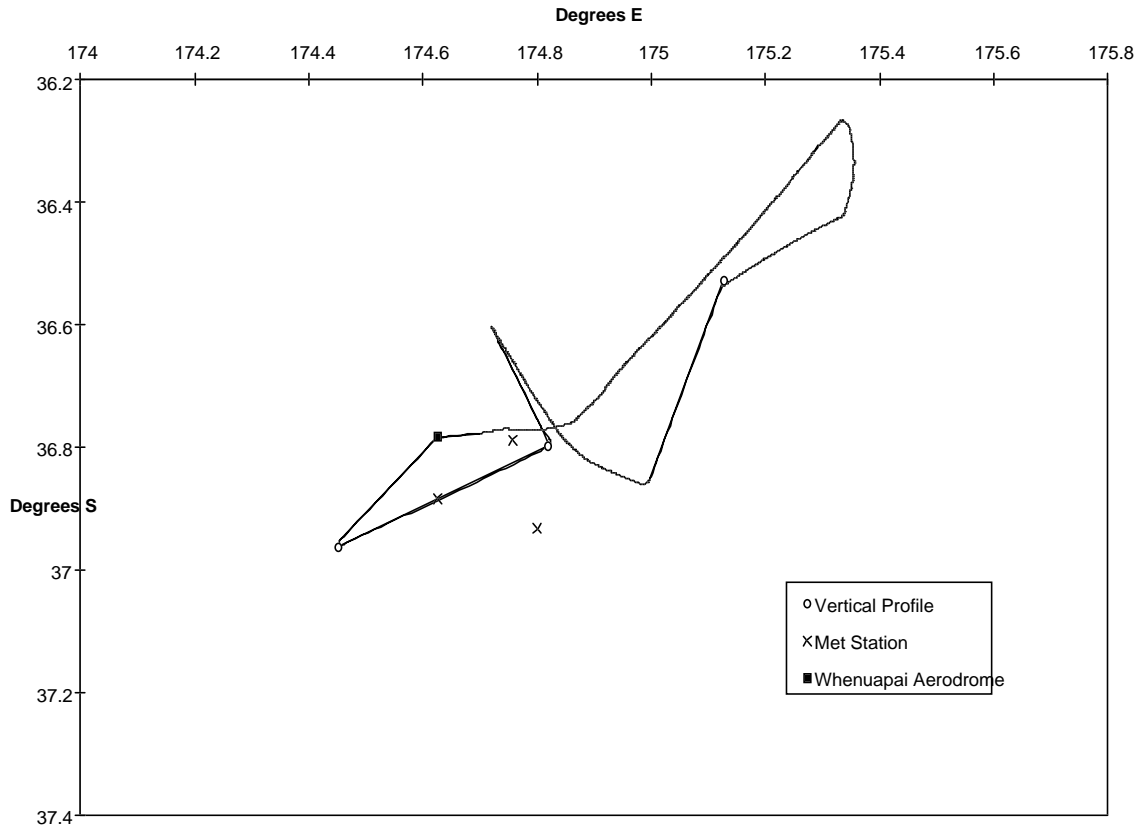


Figure 4.4: The 27th February aircraft survey path (top) and wind trajectories calculated from the Onehunga, North Shore and Henderson meteorological stations. Hourly data (bottom).

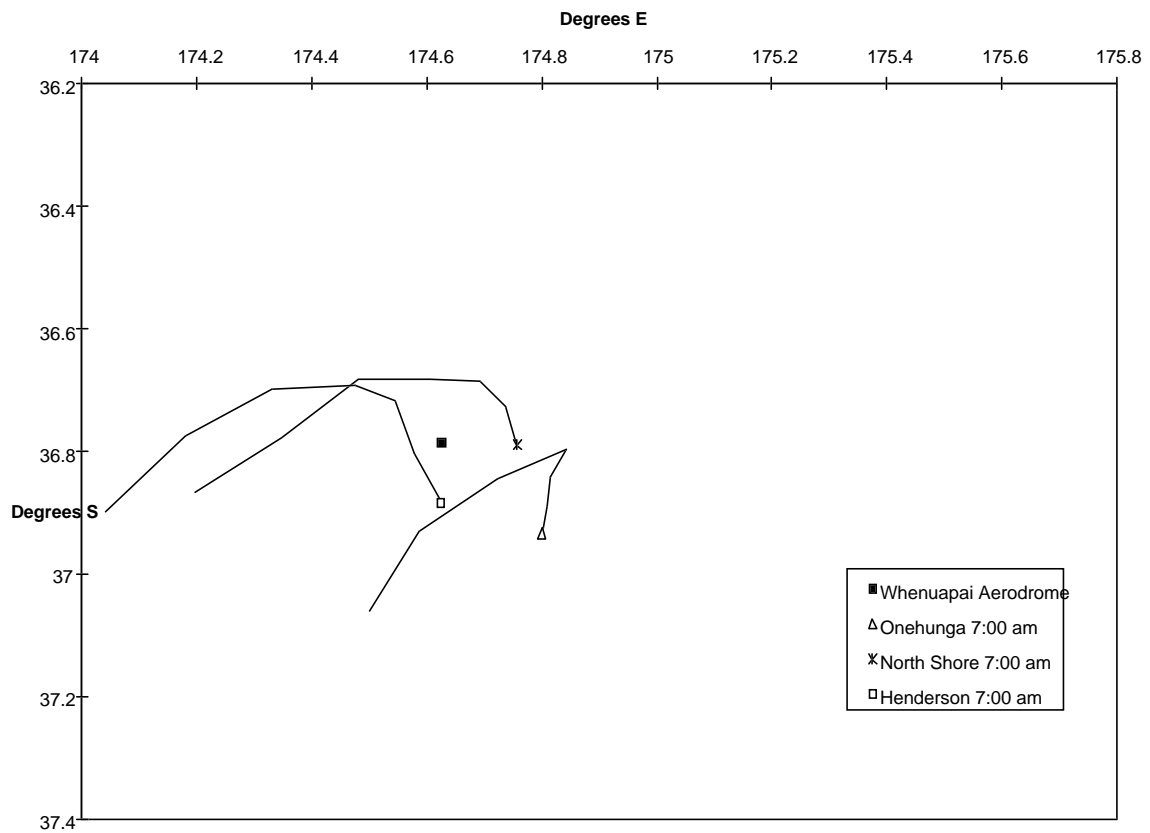
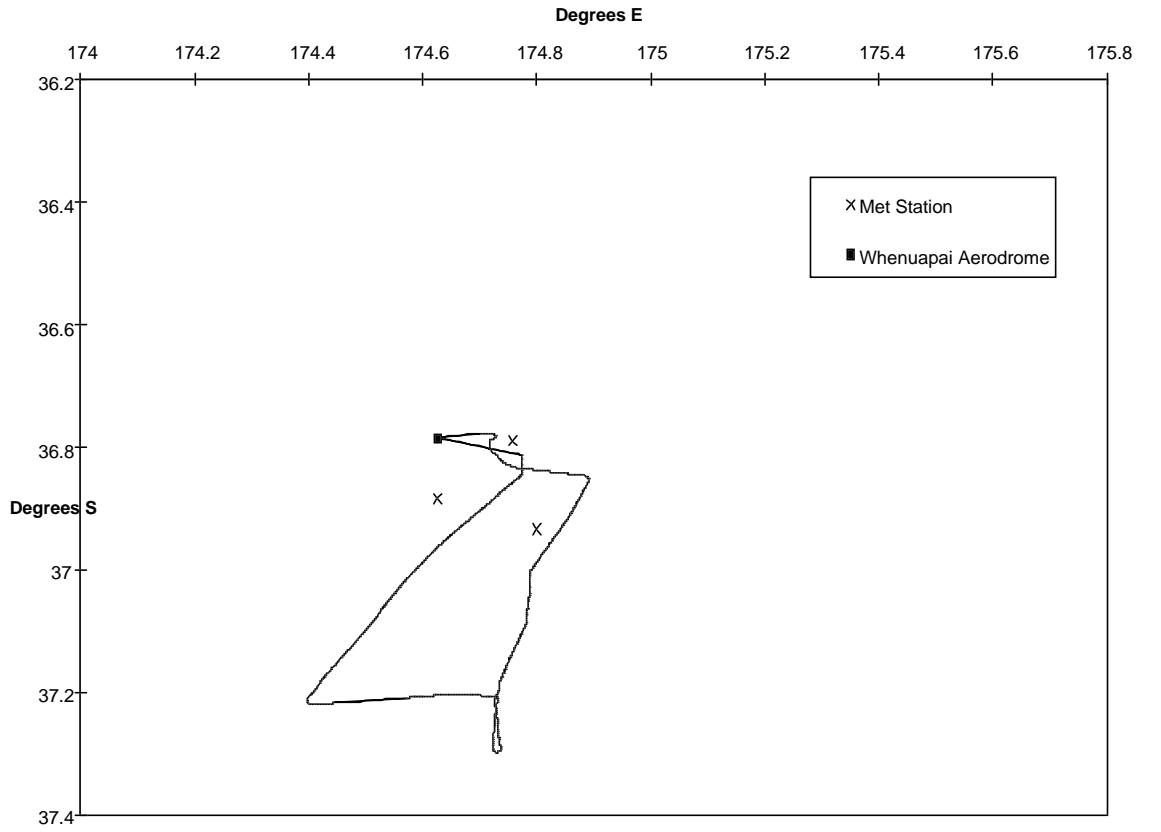


Figure 4.5: The 28th February aircraft survey path (top) and wind trajectories calculated from the Onehunga, North Shore and Henderson meteorological stations. Hourly data (bottom).

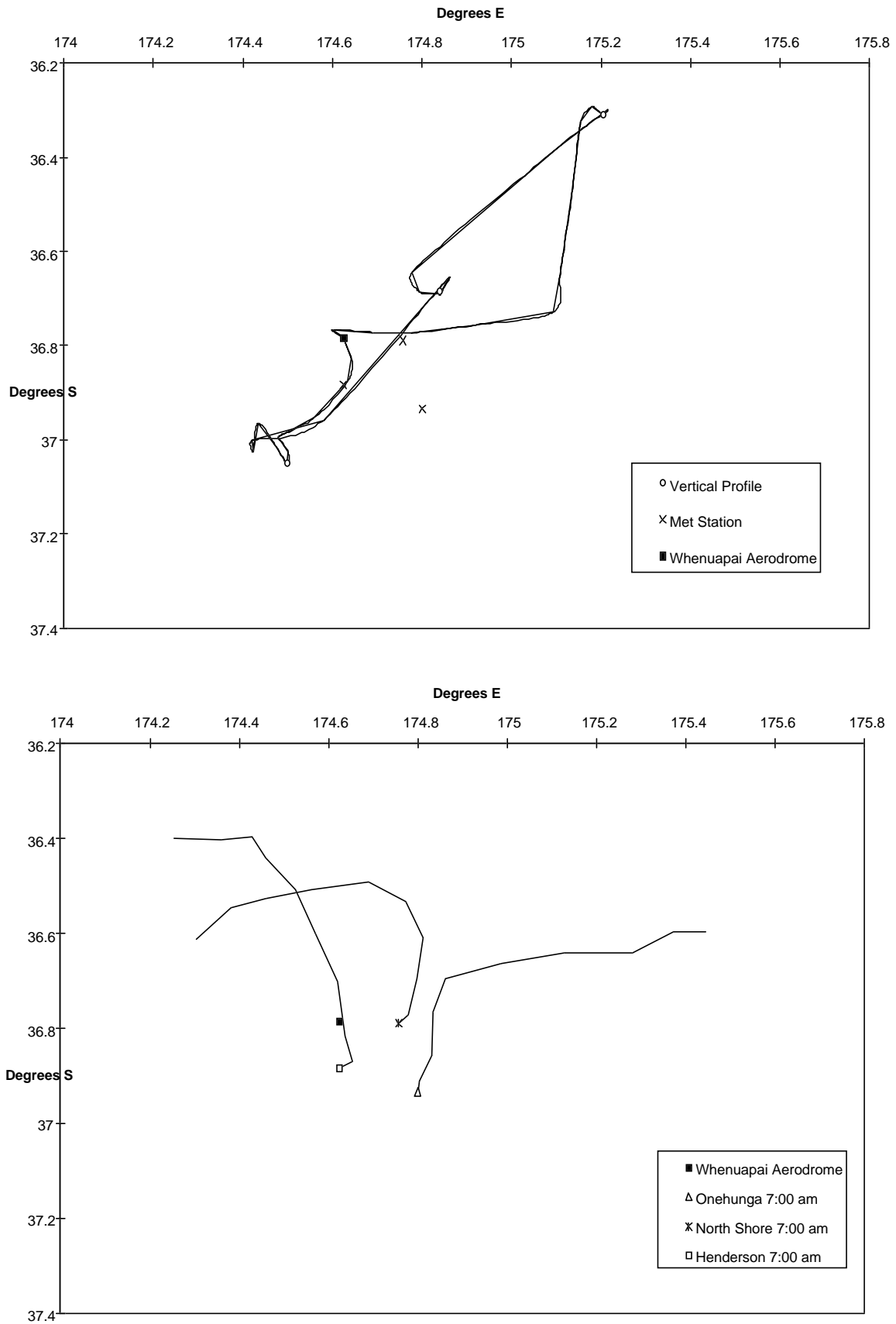


Figure 4.6: The 27th March aircraft survey path (top) and wind trajectories calculated from the Onehunga, North Shore and Henderson meteorological stations. Hourly data (bottom).

4.4 Vertical Ozone Concentration Profiles

The vertical ozone concentration profiles obtained by slow spiralling of the aircraft during the 14th February, 27th February, and 27th March flights are presented in Figure 4.7. No vertical profiles were undertaken during the 28th February monitoring period.

Three vertical profiles were completed for each sampling flight corresponding approximately to aircraft positions upwind, within, and downwind of Auckland's urban areas. These are labelled Spiral 1, Spiral 2, and Spiral 3 respectively. Figure 4.7 shows that the vertical ozone distribution is complex and varies between days and spatial locations. However, generally the recorded ozone concentrations were lower during the first spiral of a reconnaissance flight. This characteristic is likely to be attributable to the sources of precursor reactants involved in the formation of ozone predominantly being located downwind of the vertical profiles' positions.

Dramatic increases in average ozone concentrations for each of the successive spirals completed during the 27th February flight similarly supports the assumption that atmospheric residence time and position downwind are influential parameters. The absence of a similar trend being observed during the 27th March may be a result of relatively complex wind patterns influencing the mixing and distribution of the air contaminants at this time (see Figure 4.6).

Monitoring flights on the 14th February, 27th February, and 27th March show ozone concentrations peaking at 1200, 900, and 1000 metres respectively. The third spiral during the 27th March indicates that there may be multiple layers to the ozone concentration. However, given the relatively low ozone concentration gradients observed during the study it is difficult to draw firm conclusions about the vertical structure of ozone within the Auckland region from this data.

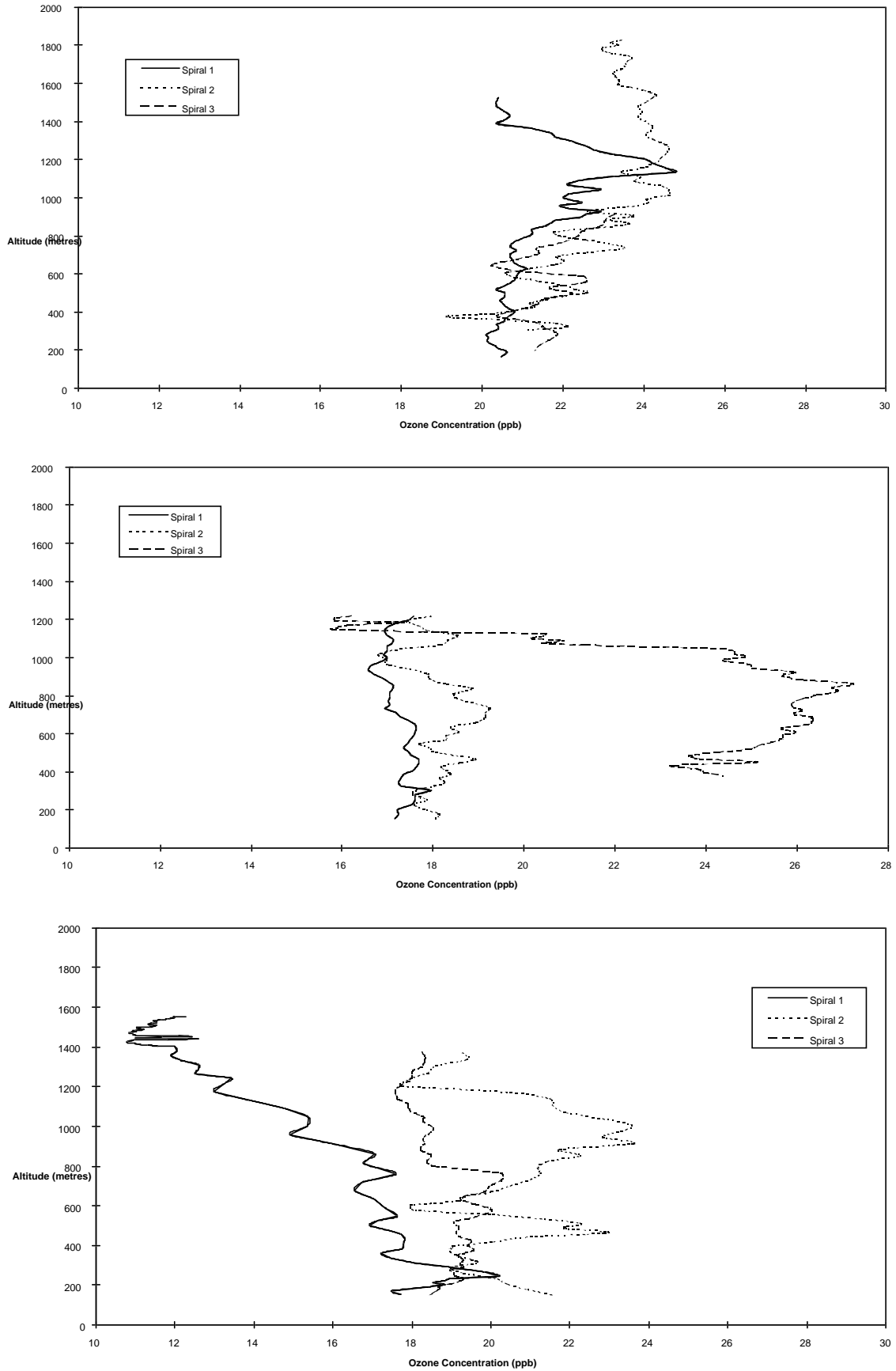


Figure 4.7: Vertical ozone concentration profiles from the 14th February (top), 27th February (middle) and 27th March (bottom) monitoring flights.

4.5 Surface Ozone Monitoring

By considering ozone concentrations measured at the Musick Pt and Pukekohe ozone monitoring stations it is possible to place the aircraft monitoring program within a broader temporal context. The average daily and maximum hourly ozone concentrations recorded at the two monitoring sites during February and March are presented in Figures 4.8 and 4.9 respectively.

Average ozone concentrations measured during February and March are summarised in Table 4.2. During the field programme the highest ozone level of 68 ppb occurred between 5:00 - 6:00 pm on Saturday the 22nd February at the Musick Pt air quality station.

	Average Daily O ₃ Concentration (ppb)		Maximum Hourly O ₃ Concentration (ppb)	
	Pukekohe	Musick Pt	Pukekohe	Musick Pt
February-March	18.2	15.7	26.2	23.9
14th February	19.5	18.3	27.2	27.1
27th February	15.1	13.9	24.3	19.5
28th February	18.6	15.9	26.0	22.6
27th March	18.2	15.4	24.7	24.3

Table 4.2: Average ground level ozone concentrations measured at the Musick Pt and Pukekohe air quality stations. February - March 1997.

Examination of these average ground level concentrations suggests that days when the aircraft ozone surveys occurred were generally representative of *average ozone conditions* within the Auckland region during February and March.

The two highest ozone days in the region, on 22nd and 24th February, both occurred on days which were not predicted to be high according to the currently accepted scheme. Both days were overcast and windy. In particular, the 22nd February was quite cool and convective clouds produced considerable rain throughout the day. As a result of this, the criteria for assessing ozone potential days may need to be revised.

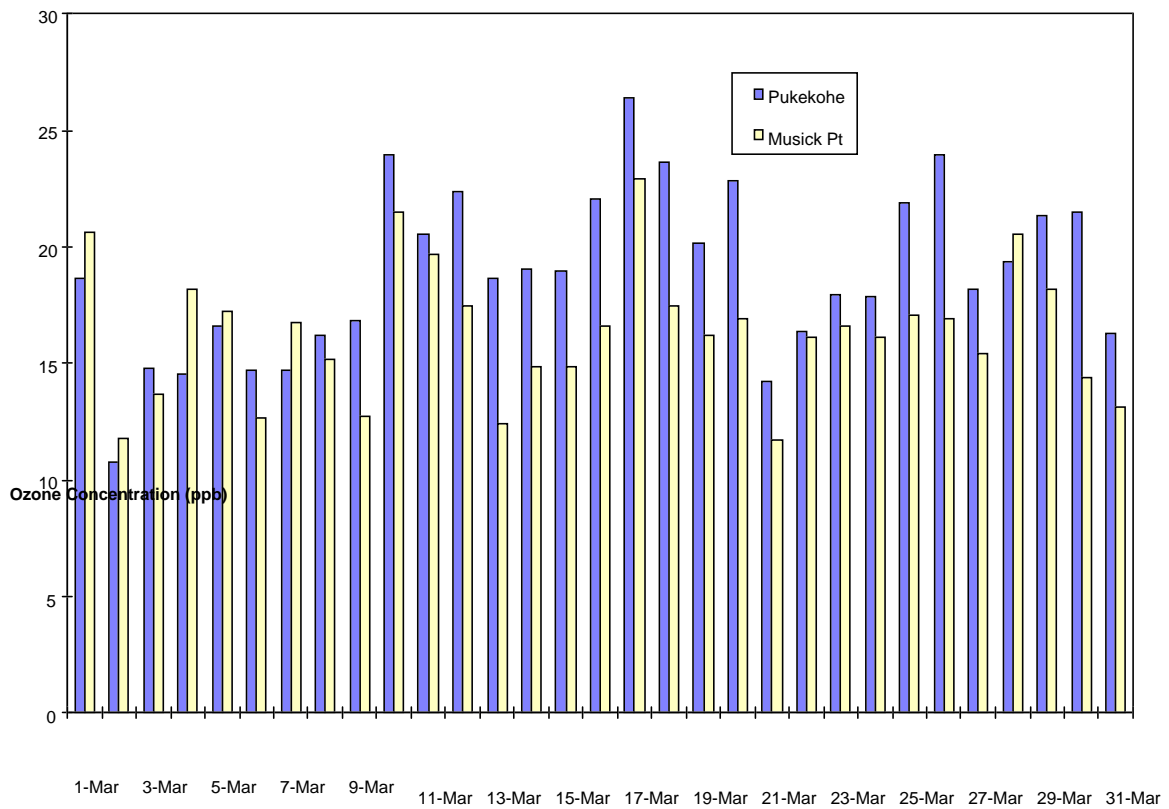
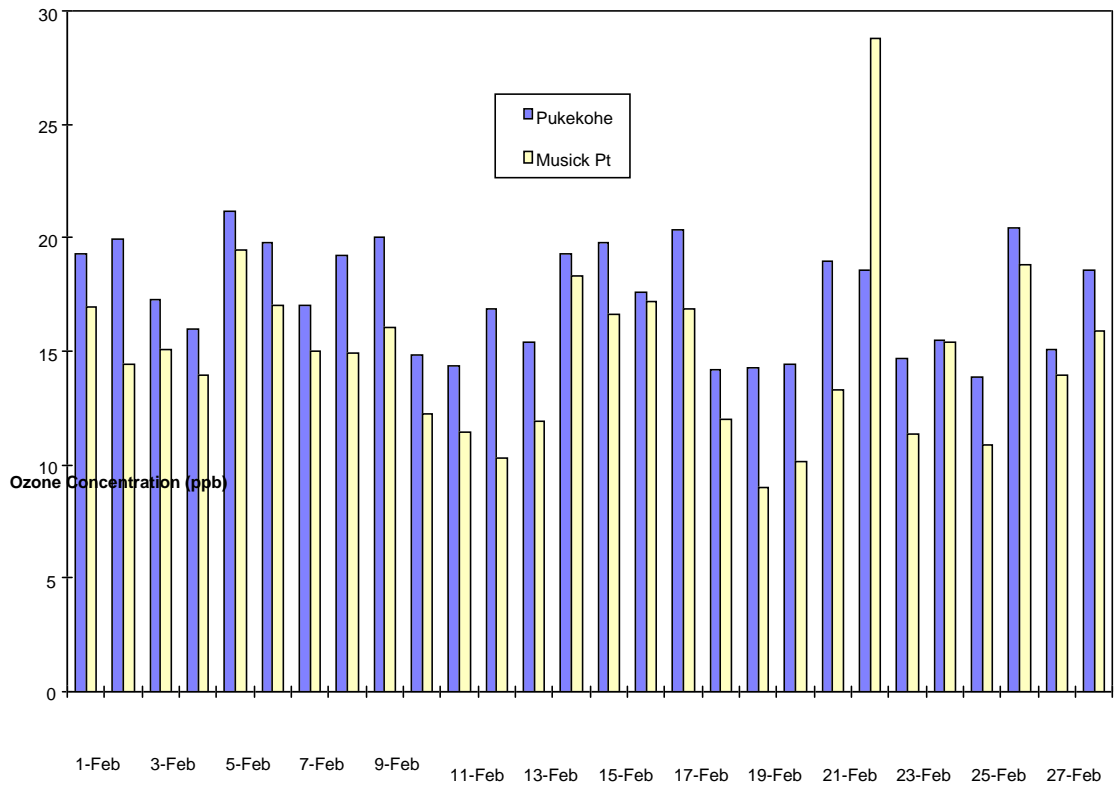


Figure 4.8: Average daily ozone concentrations (ppb) measured at the Musick Pt and Pukekohe air quality stations.

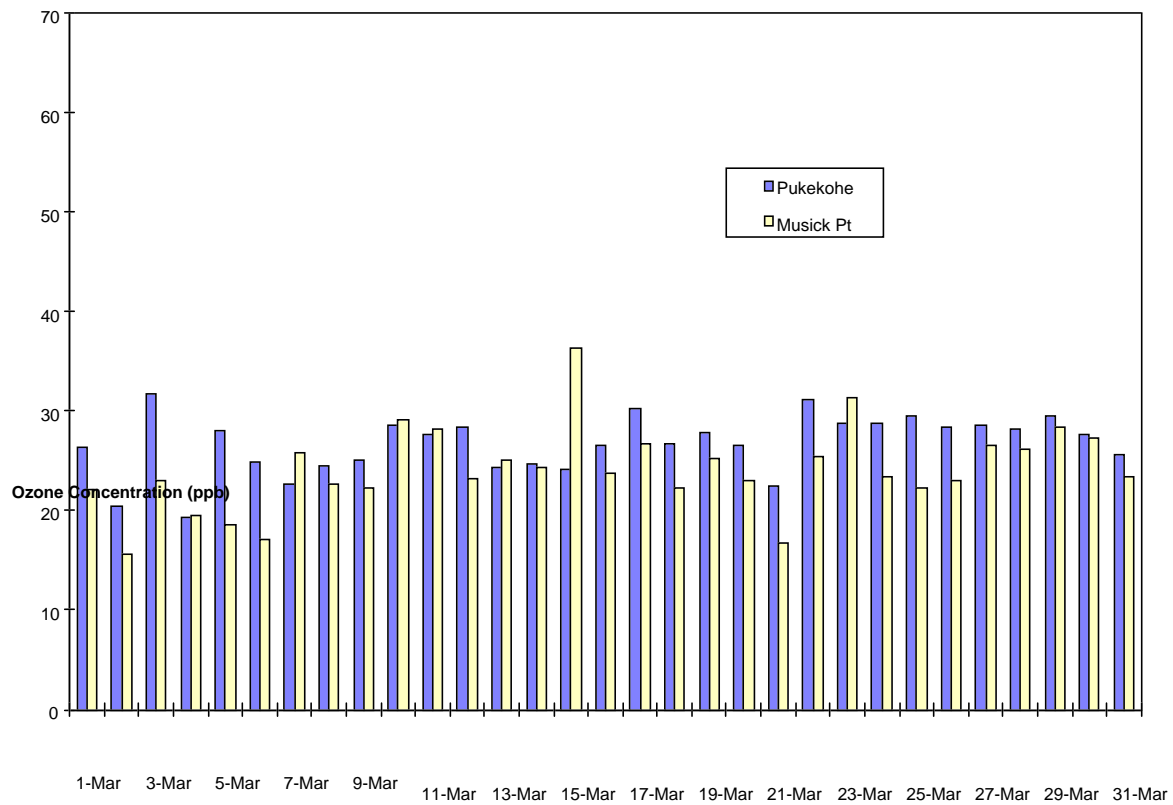
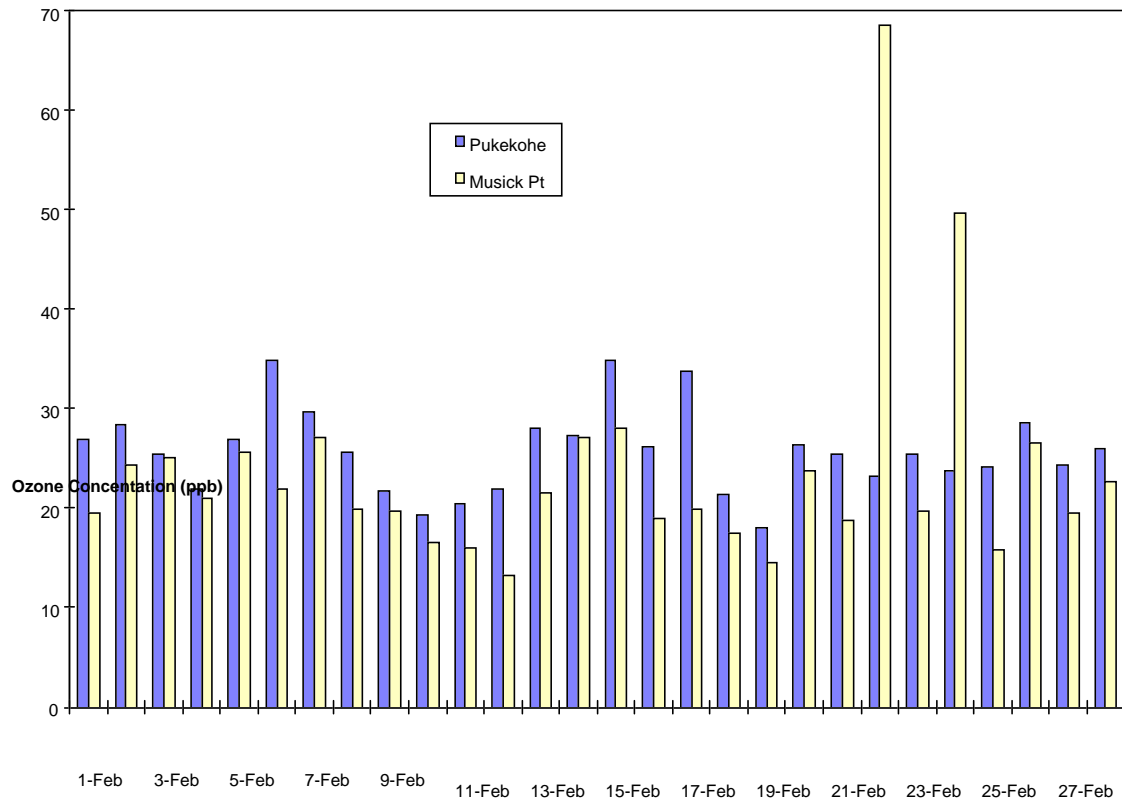


Figure 4.9: Maximum hourly ozone concentrations (ppb) measured at the Musick Pt and Pukekohe air quality stations.

5. Summary and Conclusions

This study aimed to assist the understanding of vertical and horizontal ozone distributions and augment existing data sets obtained from surface level ozone monitoring stations. The field programme operated between the 14th February and 27th March — a period of the year traditionally associated with high photochemical oxidant potentials. Within this time frame ozone monitoring flights within the Auckland region occurred upon the 14th February, 27th February, 28th February, and 27th March. The major findings of the study can be summarised as follows:

- The GFAS OS-B-2 ozonesonde provided an accurate, adaptable, robust and therefore practical option for the aircraft surveying of ozone concentrations using light aircraft. The use of the ozonesonde in conjunction with meteorological and positional instruments provides an effective method for surveying regional ozone concentrations.
- Generally only moderate ozone levels were recorded during the monitoring flights which may be partly attributed to the relatively late commencement of the monitoring programme in the summer season.
- Monitoring flights on the 27th February and 27th March showed gradual increases in ozone concentrations downwind of the central city. This may be due to ozone formation within the Auckland urban emission plume.
- Detailed vertical ozone concentration profiles were obtained via slow spiralling techniques. Examination of the profiles showed a complex and variable structure to the vertical composition of ozone. This reflects the need for further research.
- The criteria for assessing ozone potential days may have to be re-assessed, since highest values from the surface network in Auckland were found on overcast, windy days.
- A more detailed understanding of ozone within the Auckland area could be obtained from a longer sampling period and the use of a more comprehensive range of meteorological instruments installed within the aircraft.
- Ozone levels in Canterbury during the 1996/97 summer were found to be higher than those in Auckland, indicating the need for monitoring in the Canterbury region in future years.
- Overall, ozone levels found in both Auckland and Canterbury during the 1996/97 summer were within international guidelines, and thus not a cause for major concern. However a modest programme of longer term monitoring should continue, since both regions have increasing emissions of pre-cursor pollutants and are subject to weather conditions which are conducive for ozone formation.

In summary, this study has outlined basic findings regarding ozone surveys within the Auckland and Canterbury regions. The major recommendations from this study are that such methodologies can usefully be employed to assess ozone traits within the urban realm and that further research is needed to examine the complexity of the resulting data sets.

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Appendix A: Ozonesonde Specifications

Gesellschaft Fur Angewandte Systemtechnik OS-B-2 Ozonesonde Technical Data (GFAS, 1996, p17).

<u>Measuring Principle:</u>	Surface Chemiluminescence
<u>Main Application:</u>	Balloon-borne ascent and descent
<u>Atmospheric Range:</u>	Up to 50km
<u>Measuring Range:</u>	Approximately 0 - 250 ppb
<u>Detection Limit:</u>	< 1 ppb
<u>Accuracy:</u>	Approximately $\pm 5\%$
<u>Electronic Time Constant:</u>	1 second
<u>Output Signal Range:</u>	0 - 2 volts
<u>Weight:</u>	0.8 kg
<u>Dimensions:</u>	L/H/W 180/230/160 mm