# Field Validation of Inversion Estimation Techniques
# July 2011

**Contract No. DECCW-474-2010**

***Prepared by Access MQ for the NSW Office of Environment & Heritage (OEH)***

*This project has been assisted by the New South Wales Government through its Environmental Trust*

**DISCLAIMER**

# Executive Summary

The purpose of this report is to assess the validity of current practices of inversion strength estimates (extrapolations) in Camberwell NSW. Two field studies ($19^{th}$ - $22^{nd}$ of July 2010; $22^{nd}$ – $24^{th}$ of April 2011) collected tethersonde measurements during the early morning, midday, and evening on each day. Atmospheric lapse rates and associated stability classes were estimated from the tethersonde's boundary layer temperature observations at heights of 10m, 60m, and 100m above ground level.

Ashton Coal ground-based 10m and 60m a.g.l. observations made at two nearby sites during the same dates were compared to the stability classifications based upon tethersonde observations. The results show relatively good agreement between the extrapolations made by Ashton, and the observations made by the tethersonde. Discrepancies in classification were seen between Ashton's extrapolations and what the tethersonde observed, but these were confined to periods of transition when inversions were either collapsing or forming (morning and evening respectively).

Extrapolations using ground-based observations collected at 2m and 10m had predictive capability for the occurrence of inversions. However, the accuracy of the predicted lapse rate strengths was poor. This suggests the common practice of a single weather station with a 10m mast is reasonable for simple yes / no predictions of inversions, but does not accurately represent boundary layer inversion conditions. The results of this study strongly indicate that 10m and 60m observations are needed for adequate classification and reporting over the first 100m of the atmospheric boundary layer.

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# 1. Introduction

This report has been prepared by Access MQ for NSW Office of Environment & Heritage (OEH hereafter), with funding from New South Wales Government through its Environmental Trust. The purpose is to assess the validity of current practices of inversion strength estimates, i.e. extrapolations, in Camberwell NSW (Upper Hunter Valley region).

The thermal stability of the atmospheric boundary layer above the ground level greatly influences the propagation of environmental noise, as well as dispersion of ground-sourced air pollution. OEH uses vertical atmospheric temperature lapse rates to categorise stability conditions in order to administer Environment Protection Licences (EPL's) that govern noise restrictions. Most sites base their lapse rate estimates on two measurements; one near ground level, and the other typically at 10 metres above ground, corresponding to the heights of standard meteorological masts and automatic weather systems (AWS). Obtaining measurements beyond the 10m height of a meteorological mast is technically difficult and expensive, so estimates of inversion strength are usually made by extrapolating temperature differences between 2 metres and 10 metres.

In order to critically test the validity of this method of boundary layer temperature gradient extrapolation, one requires a "true" temperature profile based on instrumental measurements from near-ground all the way up to 100m. The research here used a helium-filled blimp to transport a package of meteorological instruments (tethersonde) to obtain "true" profiles.

Data collection over two campaigns (7 days total) involved direct measurements of boundary layer conditions up to 100m using three Vaisala TTS11 Tethersondes from two different sites within Camberwell in July 2010 and April 2011. This data provides information on the following:

- Atmospheric temperature observations from 2m, 10m, 60m, and 100m above ground level
- Observed lapse rates from 2m to 100m using $\Delta t / \Delta Z$ (difference in temperature across a difference in height)
- Estimated stability classes as per the NSW INP guidelines
- Boundary layer temperature differences extrapolated from ground-based observations.

## 1.2 Background

Two field studies were conducted from the 19th - 22nd of July 2010 and 22nd -24th of April 2011 between the hours of 6:00am and 7:00pm daily. Tethersonde observations were made at dawn, midday, and dusk in order to capture the full variety of stability conditions. Differences in season provided a wider sample of environmental conditions. Atmospheric lapse rates and associated stability classes were estimated from the data collected by the Vaisala TTTS111 instruments, which included direct measurements of temperature at heights of 10m, 60m, and 100m above ground level. The selection of heights was based upon current practices in environmental monitoring systems in the area, and are suitable for the calculation of stability classes administered by the EPL's.

Two sites were used in the field studies, located in the township of Camberwell, 200km north of Sydney. The town is situated in a natural depression, flanked by a ridge about 60m above the valley floor. It is in close proximity to the Ashton Coal mine, and Site 2 corresponds to the valley automatic weather station (AWS) operated by Ashton Coal. The repeater AWS on elevated terrain 56m higher than the valley AWS. **Figure 1** shows the location of each site, and **Table 1** shows elevation and coordinates for reference purposes.


**Figure 1.** The study site at Camberwell, showing the locations of the Tethersonde sites, automatic weather stations (AWS), and proximity to surrounding mines.

| | Site 1 | Site 2 |
|---|---|---|
| **Base Altitude** | 67m (a.s.l.) | 64m (a.s.l.) |
| **Latitude** | 32.47 | 32.47 |
| **Longitude** | 151.08 | 151.09 |

**Table 1**. Elevation and coordinates for the two tethersonde sites

# 2. Materials and Methods

## *2.1 Materials*

- Vaisala TT112 helium-filled blimp made of urethane plastic approximately 3m in length x 2m diameter (~7 cubic metres),
- Vaisala TTS111 Tethersonde x 3,
- Atmospheric Instrumentation Research Inc (AIR) TS-3AW electrical winch fitted with high-tensile strength lightweight cord,
- Toshiba Satellite laptop computer running Vaisala TT12SW v2.01 software,
- Vaisala 601 552 aerial
- Vaisala SPS220 Sounding Processor
- Vaisala TTD111 rapid deflation device
- Aspirated psychrometer for 2m observations and calibration of all other temperature sensors in the system.

| **General Specifications** | |
|---|---|
| **Property** | **Description / Value** |
| Dimensions | Approx 145cm x 32cm x 32cm |
| Power Source | 9 V Battery |
| Power Consumption | 100 mA |
| Weight | 300g |
| Operating Temperature | 0…+50°C |
| **Temperature Measurement Specifications** | |
| Measuring Range | -50…+60°C |
| Resolution | 0.1°C |
| Response Time | 0.2 s |
| Repeatability of Calibration | 0.1°C |

**Table 2.** Tethersonde technical specifications

**Figure 2.** Blimp and tethersonde equipment set-up

## 2.2 Methods

### 2.2.1 Procedures

The blimp was inflated with helium gas and secured to the winch with a tetherline. A rapid deflation device was attached to the blimp and set to 950hpa as a preventative measure in case the blimp broke free from its tetherline for any reason. The tethersondes were attached to the tetherine and raised at carefully measured intervals relevant to the objectives of this study: 10m, 60m and 100m.

The specific measurement heights selected for this study include those made by most automatic weather stations (2m and 10m) and the important heights for the EPL classification (60m and 100m). Observations were made for approximately two hours at each spot height, or until inclement weather forced early shut-down of observations due to increased risk of the blimp breaking the tetherline. Frequency of tethersonde data logging was at ten second intervals and then averaged into 15 minute time-steps. 2m observations were made every 15 minutes using an Assman aspirated psychrometer.

Observations were made at Site 1 from 19th through to the morning of the 21st July 2010. All the equipment was moved and set up at Site 2 for observations in the evening of the 21st and morning of the 22nd July 2010. Observations for the second campaign in April 2011 were all made at Site 2.

### 2.2.2 Data Analysis

All observed atmospheric parameters were stored in a Comma Separated ASCII file, which was imported into Microsoft Excel 2007. A filter was used to check for any discrepancies or irrelevant information in the data. Observations were organised into and averaged over 15 minute time steps, as per the NSW EPA regulations. This removed any spatial and temporal noise caused by fluctuations in observed temperature. Data collected by the tethersondes were compared with data from the ridge and valley weather stations owned by Ashton Coal.

In order to assess the validity of inversion strength estimates, spot height data was used to extrapolate to a height of 100m. This was achieved using the following formula:

$$\mathbf{\Delta t / \Delta Z = Temp_2 - Temp_1 \times (100 / height\ difference)}$$

Environmental lapse rate extrapolations were made from spot heights of 2m and 10m, and again from 10m to 60m for comparison to the observed reference environmental lapse rate observed between 10m and 100m. For example, to calculate the environmental lapse rate using 10m and 60m observations the following formula was used:

$$\Delta t / \Delta Z = Temp60m - Temp10m \times (100 / 50)$$

The 10m to 100m observed lapse rate was considered the reference for all comparisons against extrapolations. 10m was selected as the lower extrapolation for its reduced fluctuations from ground temperature and the location of noise propagation from mining activities.

The occurrence of inversion conditions (specified in INP & NRC) based on actual 10m and 100m tethersonde observations was defined as the reference against which with the various estimation procedures could be compared in a simple ‘yes / no’ test. This was coupled with stability class comparisons. Contingency tables expanded the analysis by classifying the type of any false estimates (false positive and false negative). In order to assess the accuracy of the lapse rate strength estimates, each 15 minute time step was tested against the reference tethersonde observations of strength in bands increasing by half a degree Celsius up to 4°C.

The small data set for the afternoon of the 20th July 2010 and 22nd April 2011 was due to inclement weather. Graphical representation of midday observations was combined across both campaigns because of a smaller sample size. These values are available in the appendix.

## 3. Results

| | Dawn | Midday | Dusk | TOTAL |
|---|---|---|---|---|
| Total 15 Minute Sets | 54 | 27 | 36 | 117 |
| Observed Inversions | 40 | 0 | 27 | 67 |
| A Class | 0 | 3 | 0 | 3 |
| B Class | 0 | 9 | 0 | 9 |
| C Class | 0 | 5 | 0 | 5 |
| D Class | 14 | 10 | 9 | 33 |
| E Class | 11 | 0 | 21 | 32 |
| F Class | 17 | 0 | 6 | 23 |
| G Class | 12 | 0 | 0 | 12 |

**Table 3.** Summary statistics for the observations across both campaigns.

It is important to briefly explain the concept of atmospheric lapse rate and stability in order to give the following results context. Firstly, the environmental lapse rate (ELR) is a measure of the actual temperature, as observed by the tethersonde. For example, a lapse rate of 1°C / 100m means that the atmosphere cools one degree celsius every 100m above ground level. This exhibits variations over space and time.

The stability of the atmosphere is a function of the environmental lapse rate. If an air parcel is warmer than the surrounding environmental air, it will be less dense and thus will become buoyant and rise (unstable). Conversely, if the parcel is cooler it will be denser and will therefore subside (stable). If it is the same temperature it will remain at that height and is said to be neutral.

A parcel of air will change temperature as it rises (and expands) or subside (and compresses) according to the dry adiabatic lapse rate (DALR) of ~1C / 100m. For example, an air parcel at 20C at 100m, if ascending, will cool to ~19C at 200m. If the ELR is greater than the DALR, the atmosphere is unstable; if it is less, it is stable. In clear conditions, it is normal for the atmosphere to be unstable by day and stable at night (**Figure 3**). The environmental lapse rates are included in **Appendix A**.

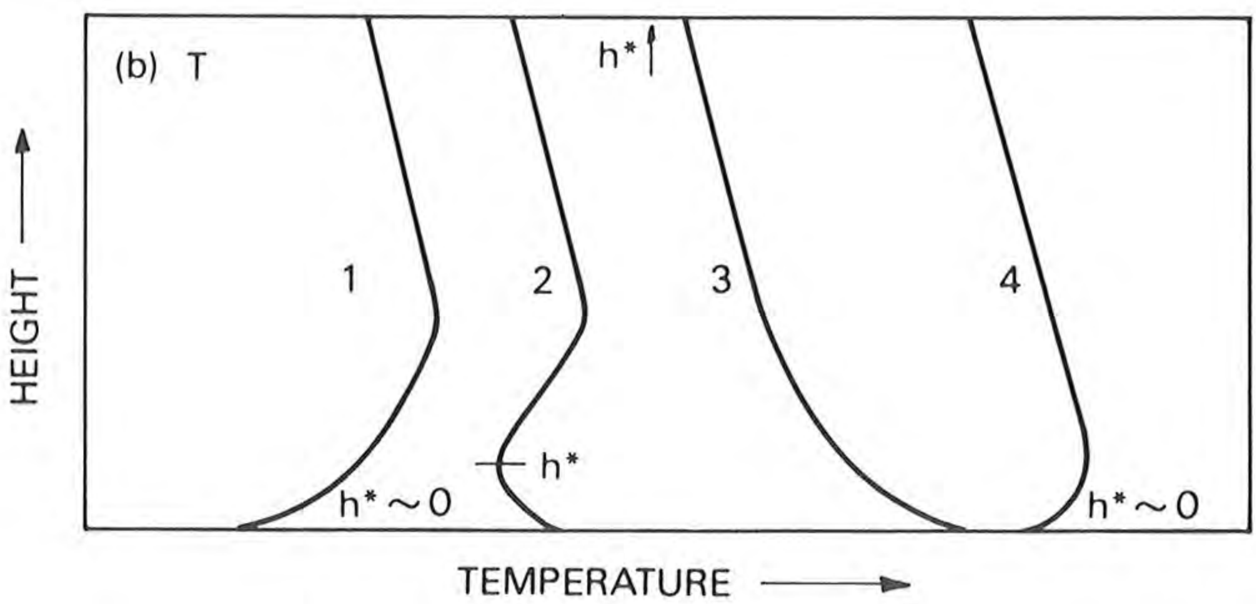



**Figure 3**. Generalised form of the air temperature profile in the lowest 150m of the atmosphere at different times on a day of fine weather. Profiles: 1 – before sunrise, 2 – soon after sunrise, 3 – midday, 4 – near sunset. The depth of the mixing layer (h*) is also indicated. (after Oke, 1987)

### *3.1 Inversion occurrence and stability classes*

From a total of 117 data points, Table 1 and Table 2 shows that extrapolations techniques do have a high level of accuracy in determining the occurrence of inversion conditions. Moreover, the 10m to 60m estimates carry an acceptable level of classification prediction. Although the 2m to 10m and Ashton's extrapolations have the same level of accuracy in 'yes/no' conditions, the stability class estimates are much lower using the 2m to 10m observations. This shows that this technique is unsuitable for lapse rate strength estimates (as shown in **Table 4** and **Table 5**) and thus inappropriate for licensing purposes.

| **Extrapolated From** | **Yes/No Inversion** | **Stability Classes** | |
|---|---|---|---|
| | | **Same** | **±1** |
| **2m to 10m observations** | 79% | 13% | 44% |
| **10m to 60m observations** | 84% | 61% | 83% |
| **Ashton's 10m to 60m observations** | 79% | 43% | 79% |

**Table 4**. Inversion occurrence and stability class estimates from extrapolation techniques. For example, extrapolations from 2 to 10m observations up to 100m lapse rates are correct in diagnosing presence or absence of inversions (Stability Classes E, F or G) 79% of the time. Stability class estimates were correct 13% of the time, and were within one class (±) 44% of the time.

| | | Tethersonde Reference Observations | |
|---|---|---|---|
| | | *Inversion* | *No Inversion* |
| Predicted | *Inversion* | 39% | 1% |
| | *No Inversion* | 42% | 18% |

| | | Tethersonde Reference Observations | |
|---|---|---|---|
| | | *Inversion* | *No Inversion* |
| Predicted | *Inversion* | 50% | 9% |
| | *No Inversion* | 33% | 7% |

| | | Tethersonde Reference Observations | |
|---|---|---|---|
| | | *Inversion* | *No Inversion* |
| Predicted | *Inversion* | 47% | 11% |
| | *No Inversion* | 32% | 10% |

**Table 5**. Contingency tables of predicted inversion status versus observed inversions. Top table refers to predictions based on 2m to 10m observations; Middle table refers to predictions based on 10m to 60m tethersonde observations; Bottom table refers to predictions based on Ashton Coal's 10m to 60m observations. For example, extrapolations from 10m to 60m predicted an inversion when there was no observed inversion 9% of the time.

In order to isolate the performance and accuracy of extrapolations, the same analysis was performed according to stability class. Each division in **Table 6** was made according to atmospheric stability: Class A-D (unstable); Class E-F (neutral to stable); Class F (very stable).

| | Correct Yes / No Inversion Prediction | Same Stability Class Prediction | ±1 Stability Class Prediction |
|---|---|---|---|
| Class A-D | 47/50 | 5/50 | 17/50 |
| Class E & F | 35/55 | 2/55 | 24/55 |
| Class G | 11/12 | 8/12 | 10/12 |

| | | | |
|---|---|---|---|
| Class A-D | 39/50 | 19/50 | 30/50 |
| Class E & F | 47/55 | 40/55 | 55/55 |
| Class G | 12/12 | 12/12 | 12/12 |

| | | | |
|---|---|---|---|
| Class A-D | 37/50 | 8/50 | 32/50 |
| Class E & F | 43/55 | 32/55 | 48/55 |
| Class G | 12/12 | 12/12 | 12/12 |

**Table 6**. Inversion estimates according to stability class. Top table refers to predictions based on 2m to 10m observations; Middle table refers to predictions based on 10m to 60m tethersonde observations; Bottom table refers to predictions based on Ashton Coal's 10m to 60m observations. For example, extrapolations from Aston's 10m to 60m observations predicted the correct stability class in a very stable atmosphere 12 out of 12 times.

Inversion formation and collapse can occur rapidly and highlights the importance of the temporal dimension. The analysis thus far was based on data averaged across 15 minute time steps. In order to assess the sensitivity of the analysis to the duration (size) of the time steps, the same extrapolation techniques were conducted using hourly averages. The results in **Appendix B** are very similar to the 15 minute averages presented earlier, suggesting that 15 minute averages are an acceptable resolution. It is possible that higher resolution averaging would have different results.

### *3.2 Environmental lapse rate estimates*

The dataset provided by Ashton Coal was valuable for comparison, but their fortuitous proximal location of weather stations at significantly different heights is generally not available to other mining locations in this region. In order to give this study broader applicability, calculations of environmental lapse rates were made by extrapolating observed data from the tethersonde (which provided 10m, 60m, and 100m observations). These were compared against the observed (10m to 100m) lapse rate and their discrepancy classified into different categories.

| Extrapolated From | ±0.5°C | ±1°C | ±1.5°C | ±2°C | ±2.5°C | ±3°C | ±3.5°C | ±4°C |
|---|---|---|---|---|---|---|---|---|
| **2m to 10m observations** | 3% | 8% | 8% | 11% | 15% | 16% | 17% | 21% |
| **10m to 60m observations** | 56% | 77% | 87% | 90% | 98% | 100% | 100% | 100% |
| **Ashton's 10m to 60m observations** | 28% | 55% | 76% | 91% | 95% | 97% | 100% | 100% |

**Table 7**. Accuracy of ELR estimates compared to the reference tethersonde observations (10m to 100m). For example, extrapolations from 10m to 60m were within 1°C (plus or minus) of the actual lapse rate 77% of the time.

Extrapolations using 2m and 10m in **Table 7** appear to be quite inaccurate at estimating lapse rate strength, which suggests that the common practice of a single automatic weather station with a 10m mast is unable to properly diagnose 100m atmospheric boundary layer inversions conditions. From these results, it is clear that 10m and 60m observations are needed for accurate calculations of temperature lapse rates over 100m using the current formula.

### *3.3 Comparison of tethersonde observations to Ashton AWS estimates*

The siting of Ashton Coal's two automatic weather stations takes advantage of the Camberwell area's terrain by placing one station at the valley floor and the other on top of the ridge (56m higher). Despite the horizontal displacement (405m) of Ashton's two observation heights, the results show relatively good agreement between the extrapolations made by Ashton and the observations from the tethersonde.

The agreement in trends is quite good, but the calculations based on Ashton's two AWS sites appears to consistently under-predict inversion strength during the early morning transitionary periods (**Appendix C**). Once the inversion was formed the discrepancy between predicted and observed inversion strength was minimised. The stability class estimates demonstrated a similar trend.

## 4. Conclusion

The results of this study have shown that extrapolations using 2m and 10m observations do not accurately diagnose the thermal stratification occurring within the first 100m of the atmospheric boundary layer. The large diurnal fluctuations in ground temperature, particularly at the important times of sunrise and sunset, compared to the relative homogeneity of the 60-100m layer of the atmospheric boundary layer suggest that the optimum spot height options considered in this study for the purpose of estimating 10-100m temperature lapse rates are 10m and 60m.

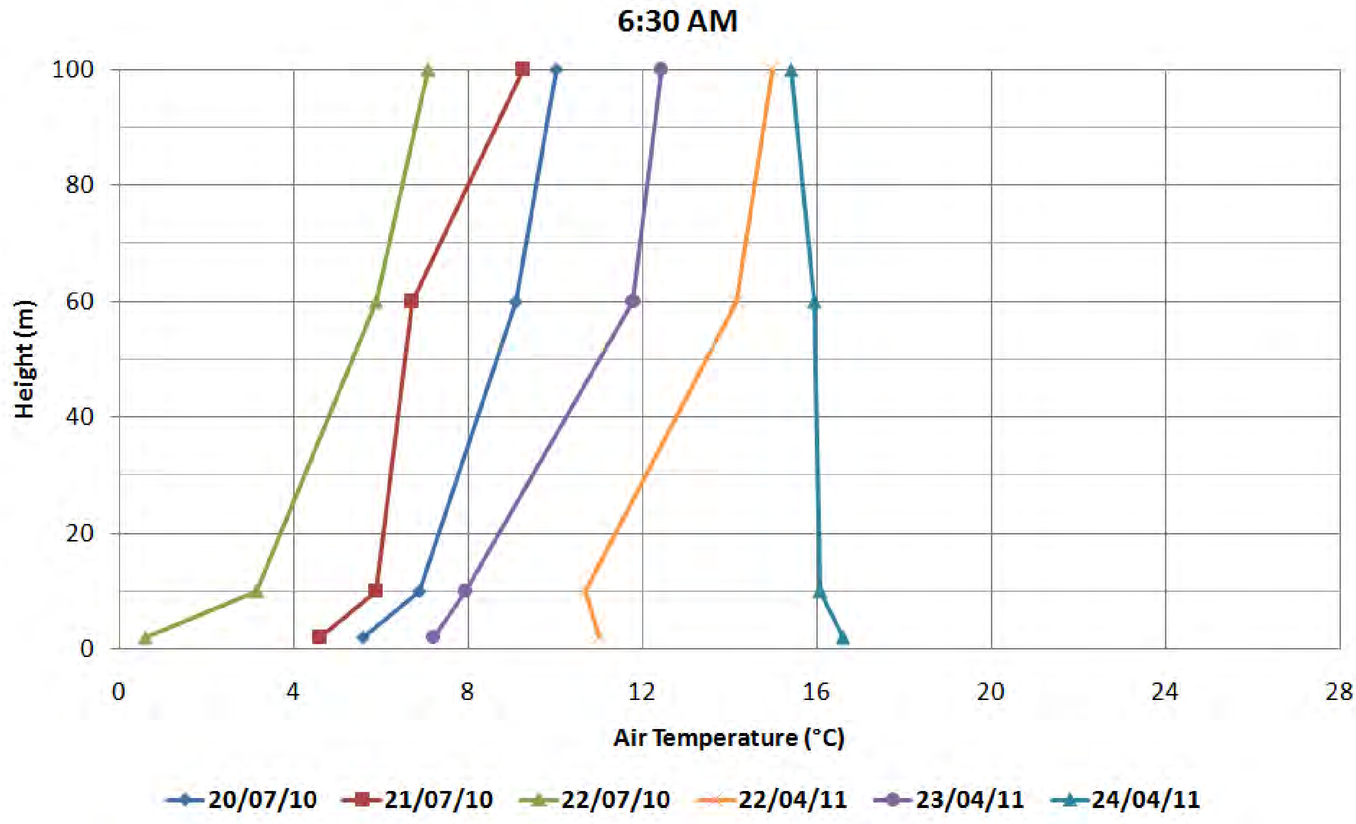
# 5. References

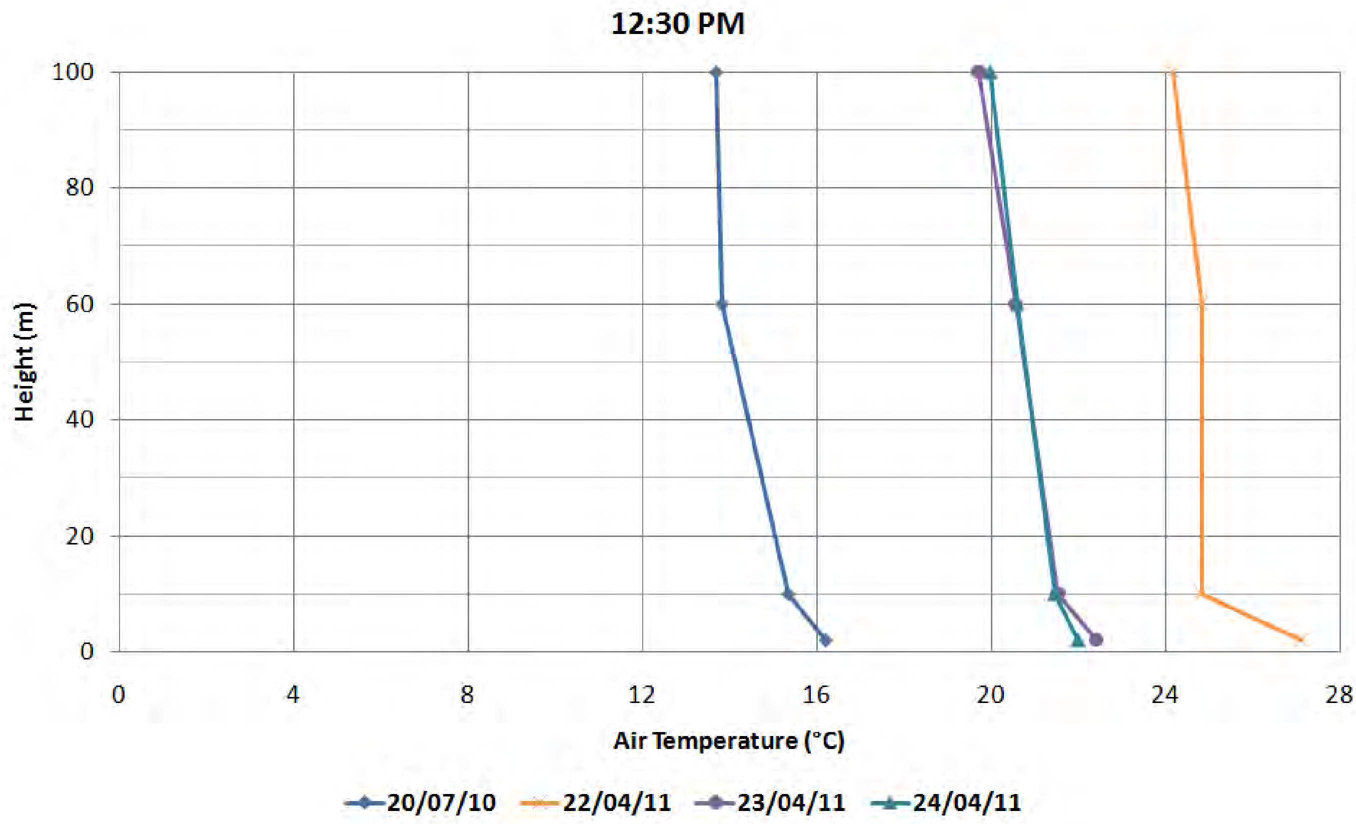
Oke, T.R. 1987. Boundary Layer Climates, 2nd Edition, Metheun, London

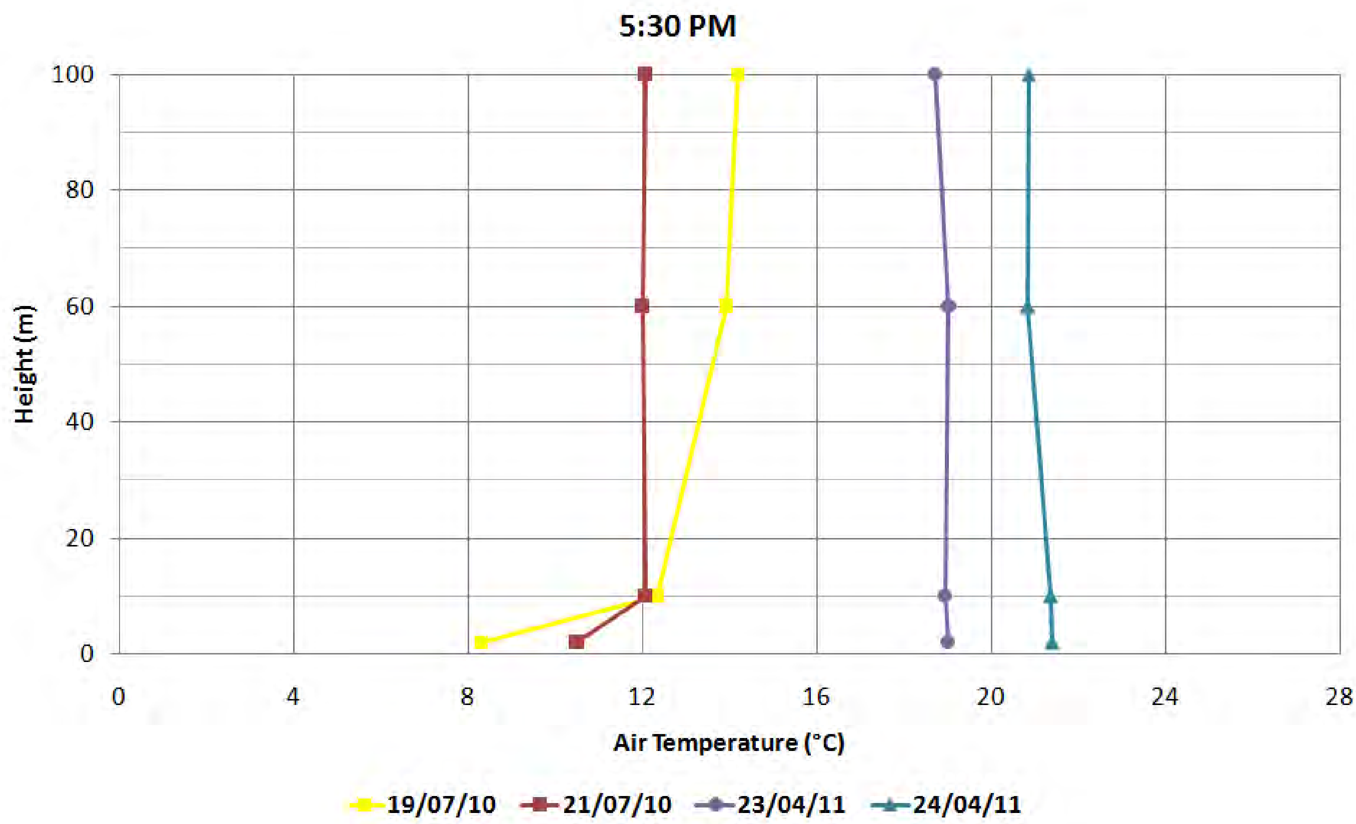
NRC (2007) Meteorological monitoring programs for nuclear power plants. Regulatory Guide 1.23, U.S. Nuclear Regulatory Commission, Washington, D.C.

INP (1999) NSW Industrial Noise Policy, Environmental Protection Authority, Sydney Australia

# Appendix A - Vertical Temperature Profiles





5:30 PM
Height (m)
100
80
60
40
20
0
0
4
8
12
16
20
24
28
Air Temperature (°C)
19/07/10
21/07/10
23/04/11
24/04/11

# Appendix B - Hourly Analyses

| Extrapolated From | Yes/No Inversion | Stability Classes | |
|---|---|---|---|
| | | Same | ±1 |
| 2m to 10m observations | 82% | 14% | 36% |
| 10m to 60m observations | 89% | 61% | 61% |
| Ashton's 10m to 60m observations | 79% | 43% | 79% |

Inversion occurrence and stability class estimates from extrapolation techniques. For example, extrapolations from 2 to 10m observations up to 100m lapse rates are correct in diagnosing presence or absence of inversions (Stability Classes E, F or G) 82% of the time. Stability class estimates were correct 13% of the time, and were within one class (±) 36% of the time.

| | | Tethersonde Reference Observations | |
|---|---|---|---|
| | | *Inversion* | *No Inversion* |
| Predicted | *Inversion* | 39% | 4% |
| | *No Inversion* | 39% | 18% |

| | | Tethersonde Reference Observations | |
|---|---|---|---|
| | | *Inversion* | *No Inversion* |
| Predicted | *Inversion* | 54% | 7% |
| | *No Inversion* | 32% | 7% |

| | | Tethersonde Reference Observations | |
|---|---|---|---|
| | | *Inversion* | *No Inversion* |
| Predicted | *Inversion* | 54% | 7% |
| | *No Inversion* | 25% | 14% |

Contingency tables of predicted inversion status versus observed inversions. Top table refers to predictions based on 2m to 10m observations; Middle table refers to predictions based on 10m to 60m tethersonde observations; Bottom table refers to predictions based on Ashton Coal's 10m to 60m observations. For example, extrapolations from 10m to 60m predicted an inversion when there was no observed inversion 7% of the time.

| | Correct Yes / No Inversion Prediction | Same Stability Class Prediction | ±1 Stability Class Prediction |
|---|---|---|---|
| Class A-D | 11/11 | 1/11 | 3/11 |
| Class E & F | 10/15 | 1/15 | 5/15 |
| Class G | 2/2 | 2/2 | 2/2 |

| | | | |
|---|---|---|---|
| Class A-D | 9/11 | 4/11 | 3/11 |
| Class E & F | 14/15 | 11/15 | 12/15 |
| Class G | 2/2 | 2/2 | 2/2 |

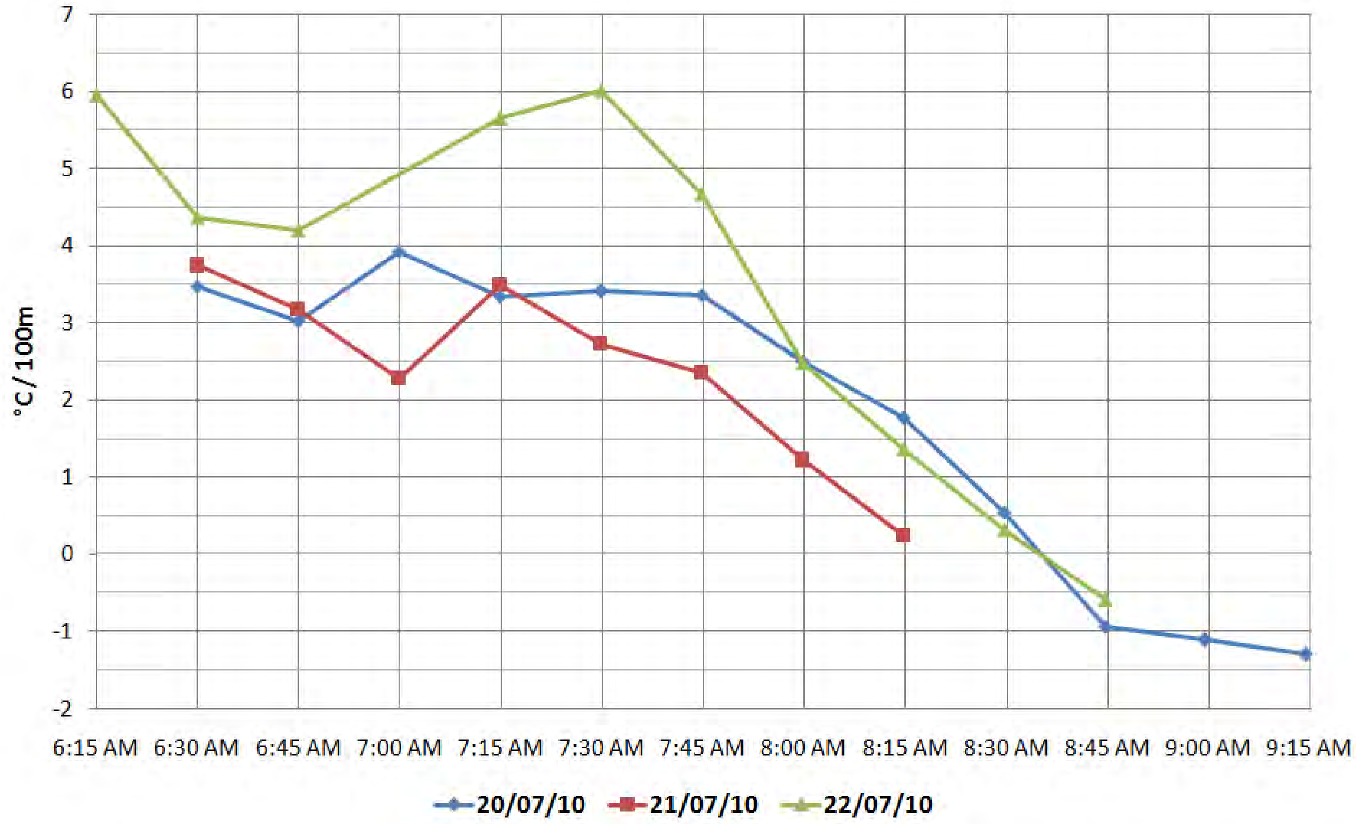
| | | | |
|---|---|---|---|
| Class A-D | 8/11 | 2/11 | 6/11 |
| Class E & F | 12/15 | 9/15 | 14/15 |
| Class G | 2/2 | 2/2 | 2/2 |

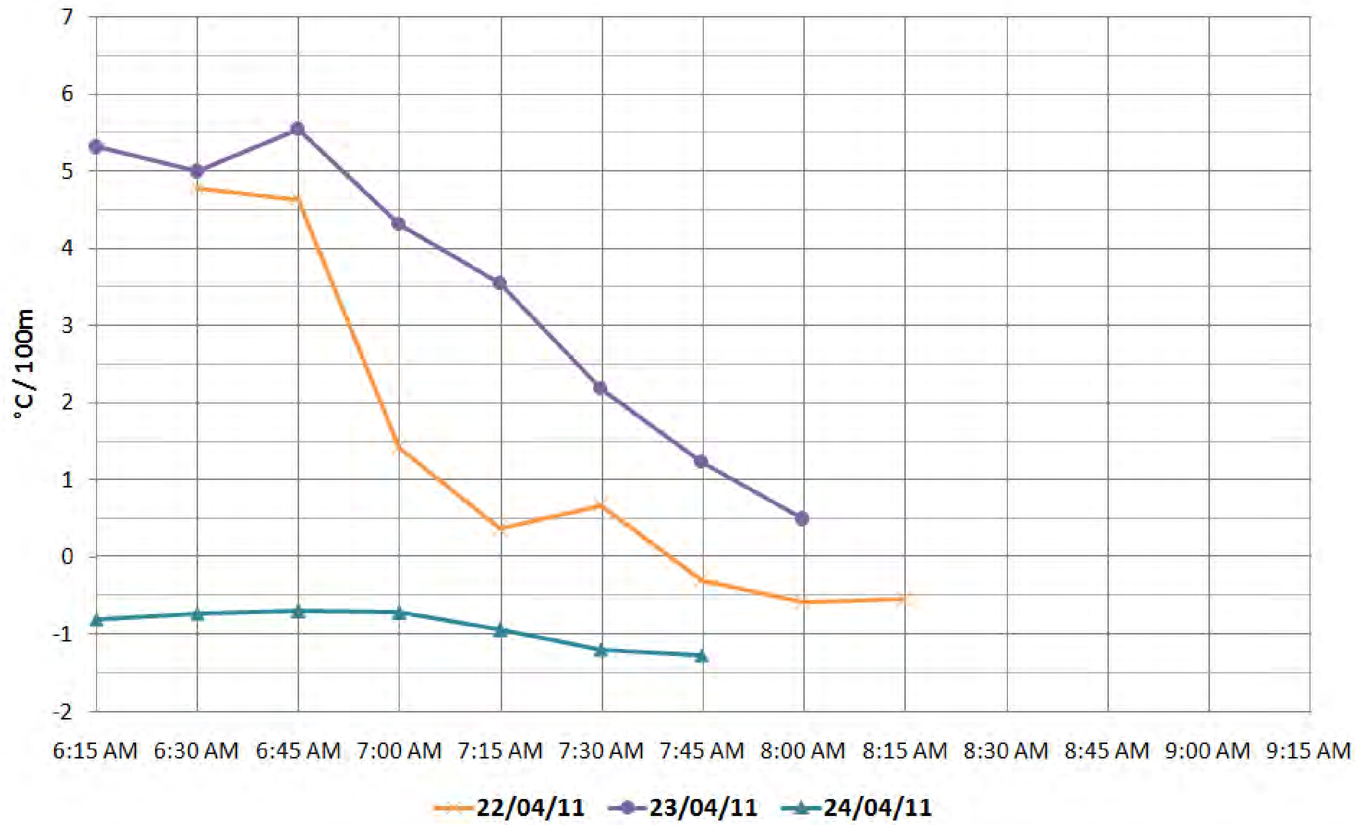
Inversion estimates according to stability class. Top table refers to predictions based on 2m to 10m observations; Middle table refers to predictions based on 10m to 60m tethersonde observations; Bottom table refers to predictions based on Ashton Coal's 10m to 60m observations. For example, extrapolations from Aston's 10m to 60m observations predicted the correct stability class in a very stable atmosphere 2 out of 2 times.

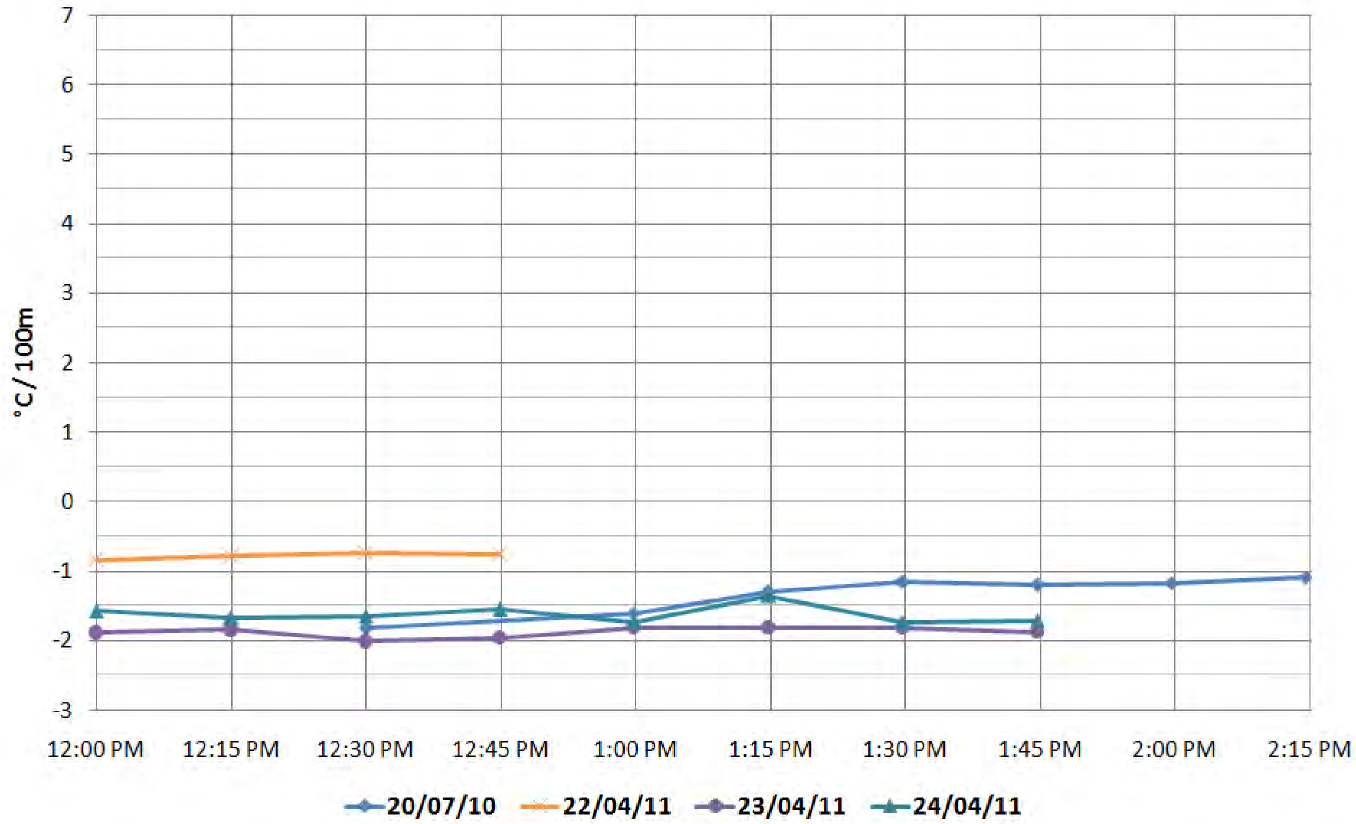
| Extrapolated From | ±*0.5°C* | ±*1°C* | ±*1.5°C* | ±*2°C* | ±*2.5°C* | ±*3°C* | ±*3.5°C* |
|---|---|---|---|---|---|---|---|
| 2m to 10m observations | 0% | 7% | 11% | 18% | 18% | 18% | 21% |
| 10m to 60m observations | 54% | 82% | 89% | 89% | 100% | 100% | 100% |
| Ashton's 10m to 60m observations | 32% | 46% | 71% | 93% | 93% | 96% | 96% |

Accuracy of ELR estimates compared to the reference tethersonde observations (10m to 100m). For example, extrapolations from 10m to 60m were within 1°C (plus or minus) of the actual lapse rate 82% of the time.

# Appendix C - Ashton AWS Estimates





7
6
5
4
3
2
1
0
-1
-2
-3
°C / 100m
12:00 PM
12:15 PM
12:30 PM
12:45 PM
1:00 PM
1:15 PM
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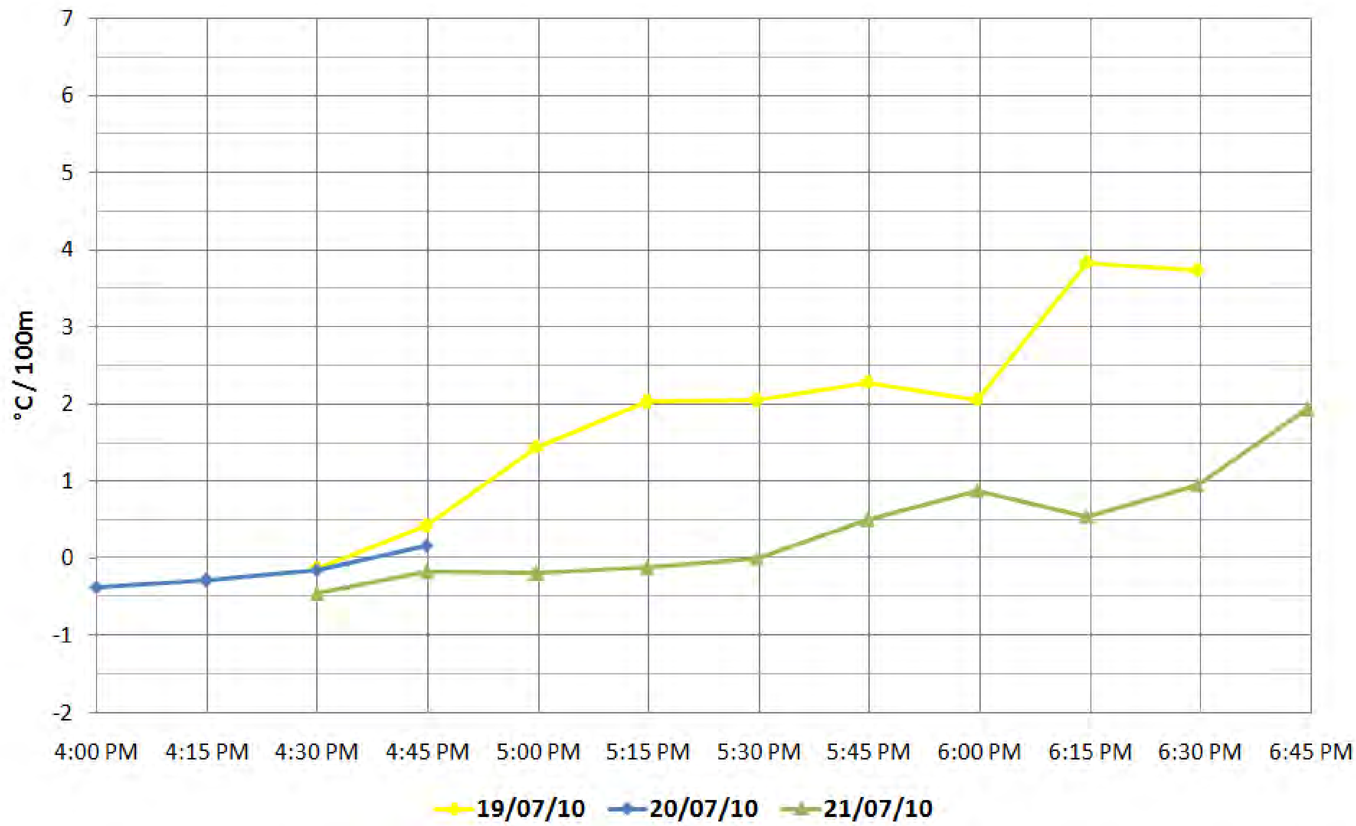
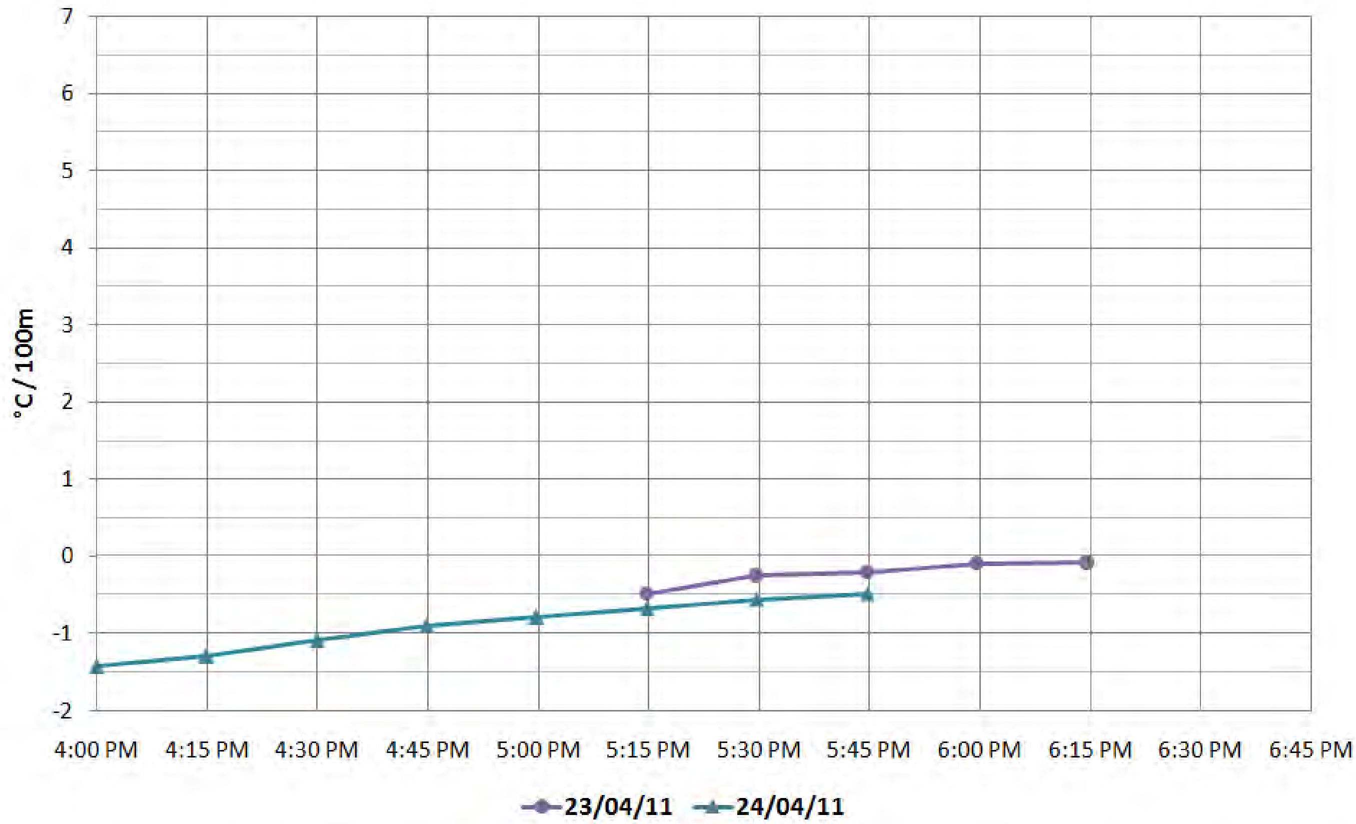
1:45 PM
2:00 PM
2:15 PM
20/07/10
22/04/11
23/04/11
24/04/11

7
6
5
4
3
2
1
0
-1
-2
°C / 100m
4:00 PM
4:15 PM
4:30 PM
4:45 PM
5:00 PM
5:15 PM
5:30 PM
5:45 PM
6:00 PM
6:15 PM
6:30 PM
6:45 PM
19/07/10
20/07/10
21/07/10



7
6
5
4
3
2
1
0
-1
-2
°C / 100m
4:00 PM
4:15 PM
4:30 PM
4:45 PM
5:00 PM
5:15 PM
5:30 PM
5:45 PM
6:00 PM
6:15 PM
6:30 PM
6:45 PM
23/04/11
24/04/11

# Appendix E Methods for determining the frequency of temperature inversions

## E1 Background

An important part of the assessment of noise enhancement due to inversions involves determining whether inversions occur frequently enough to warrant inclusion in the assessment. It is considered unreasonable to expect a development to comply with noise limits under inversion conditions if inversions occur infrequently.

The frequency of occurrence of temperature inversions may be determined either by direct measurement of inversion parameters, or by using indirect methods that allow the prediction of wind and temperature profiles to within a moderately narrow range using readily available meteorological data. The direct-measurement method will result in actual temperature gradients and drainage-flow-wind speeds from which the percentage occurrence of inversions may be determined. The indirect methods, on the other hand, allow the susceptibility of an area to inversions to be determined through the use of the relationship developed by the US Atomic Energy Commission between atmospheric stability categories and inversions. The relationship shown in *Table E1* outlines the range of temperature gradients that can be expected within each stability category. Hence, if a stability category is known, then the range of possible temperature gradients may be inferred.

A positive temperature gradient signifies a temperature inversion; hence, from the table below, inversions occur during E, F and G stability categories. These three categories are considered to represent weak, moderate and strong inversions respectively. For noise-assessment purposes, only moderate and strong inversions are considered significant enough to require assessment.

**Table E1. Stability categories based on DT/DZ**

| Stability category | Range of vertical temperature gradient (°C/100 m) |
|---|---|
| A | DT/DZ < –1.9 |
| B | –1.9 ≤ DT/DZ < –1.7 |
| C | –1.7 ≤DT/DZ < –1.5 |
| D | –1.5 ≤ DT/DZ < –0.5 |
| E | –0 .5 ≤ DT/DZ < 1.5 |
| F | 1.5 ≤ DT/DZ < 4.0 |
| G | 4.0 ≤ DT/DZ |

Three basic schemes may be used to determine the occurrence of different stability classes at a particular site based on the following combinations of meteorological parameters:

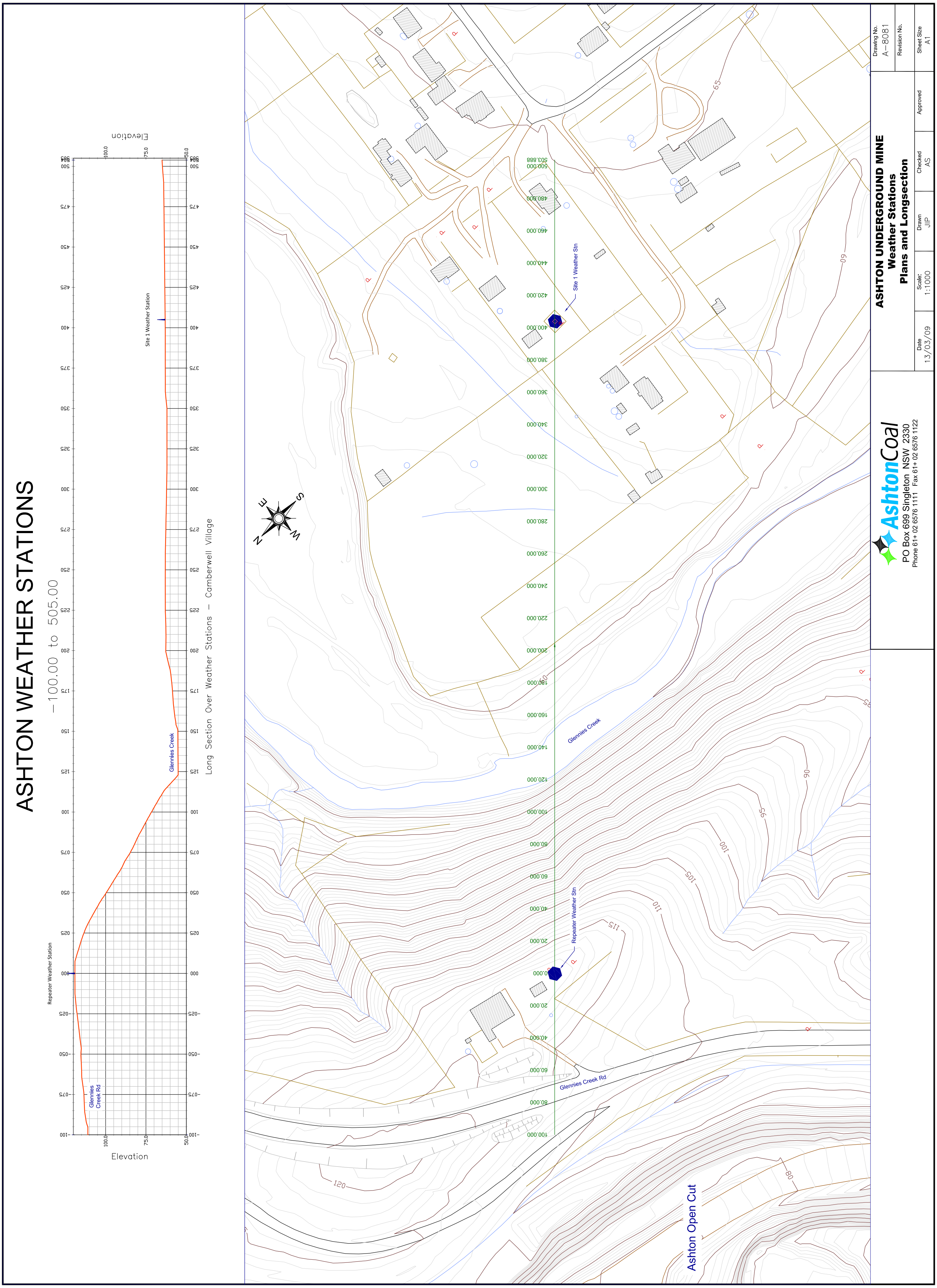
1. Direct measurement of temperature lapse rate over the height interval range of 1.5 to 10 m and 50 to 60 m, and wind speed at 10 m height.
2. Cloud cover, wind speed and solar elevation (Pasquill-Gifford scheme and Turner scheme).
3. Measurements of sigma-theta (the standard deviation of wind direction), wind speed and time of day.

All methods involve analysing three months of meteorological data collected in winter—the season during which most inversions occur. Wind measurements are to comply with AS 2923, *Ambient Air—Guide for measurement of horizontal wind for air quality applications*.

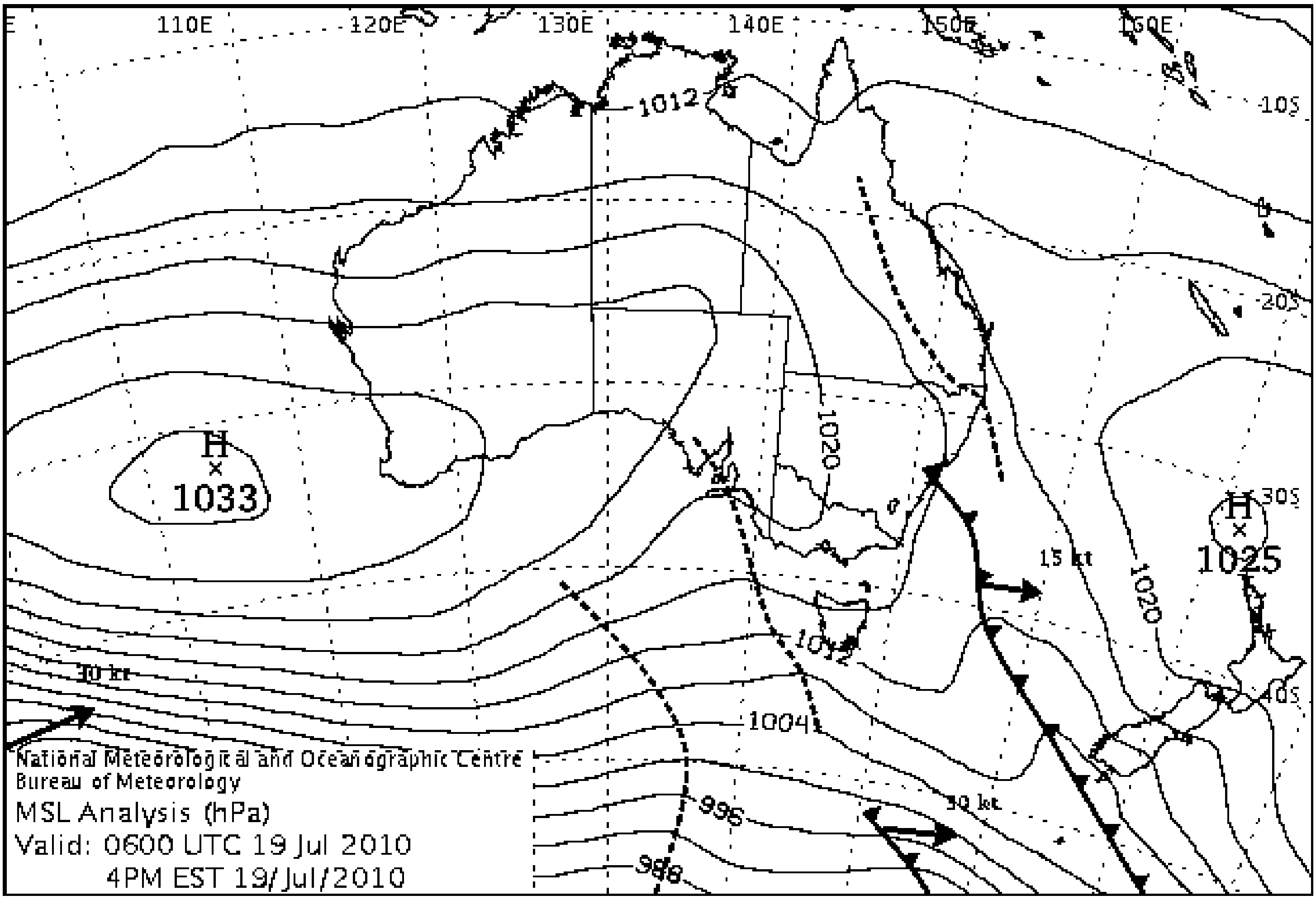
## E2 Direct measurement of temperature lapse rate

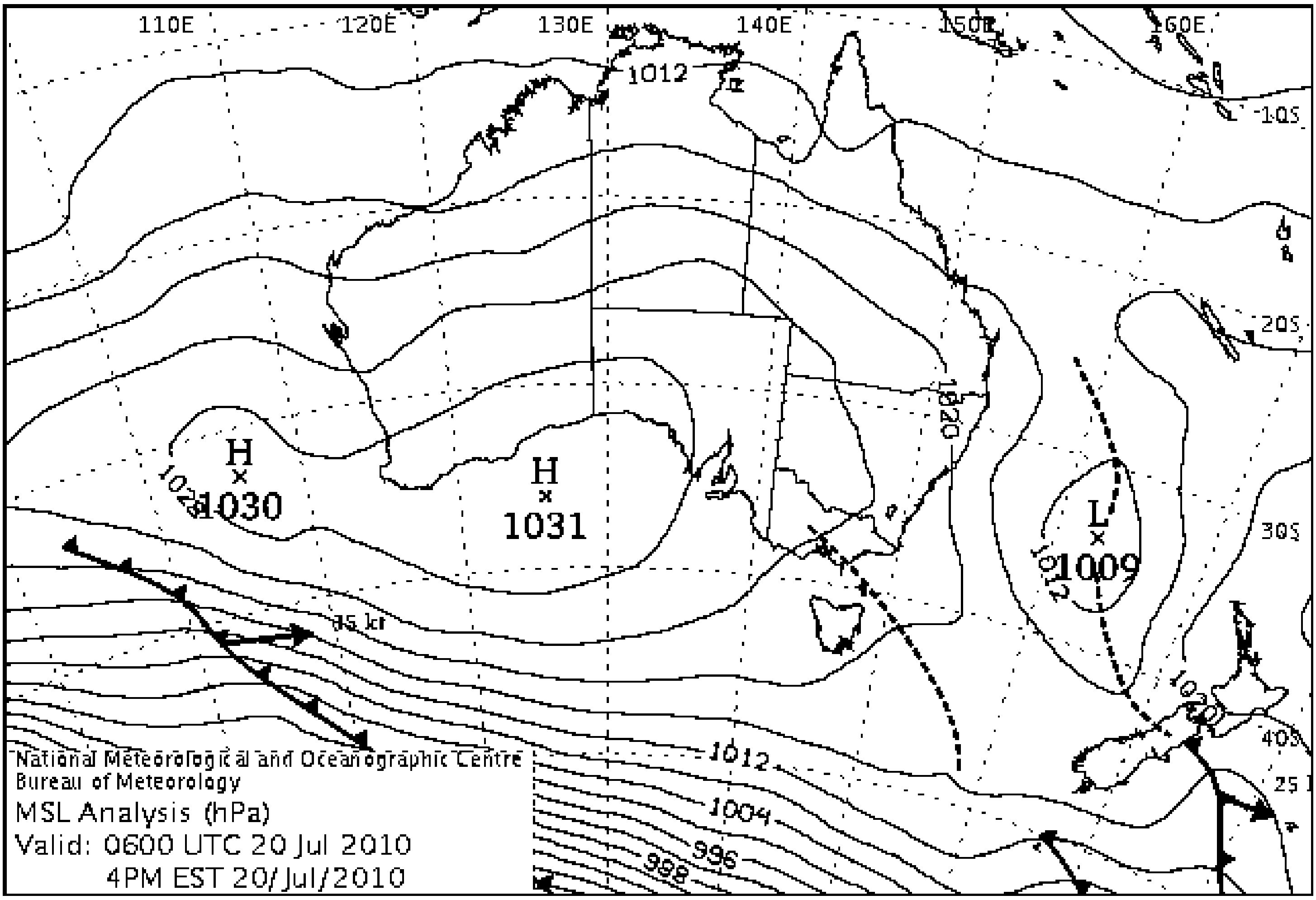
This method involves the measurement of temperature gradient and wind speed at hourly intervals over the three winter months. The temperature gradient measurement involves measuring temperature at two elevated levels (1.5 to 10 m and 50 to 60 m) over a 50-m height interval to determine the temperature difference. The temperature gradient is then the temperature difference (that is, the temperature at the higher elevation minus the temperature at the lower elevation) divided by the height difference. The wind speed should be measured at a height of 10 m. Care should be taken to ensure that measurement procedures comply with relevant standards.

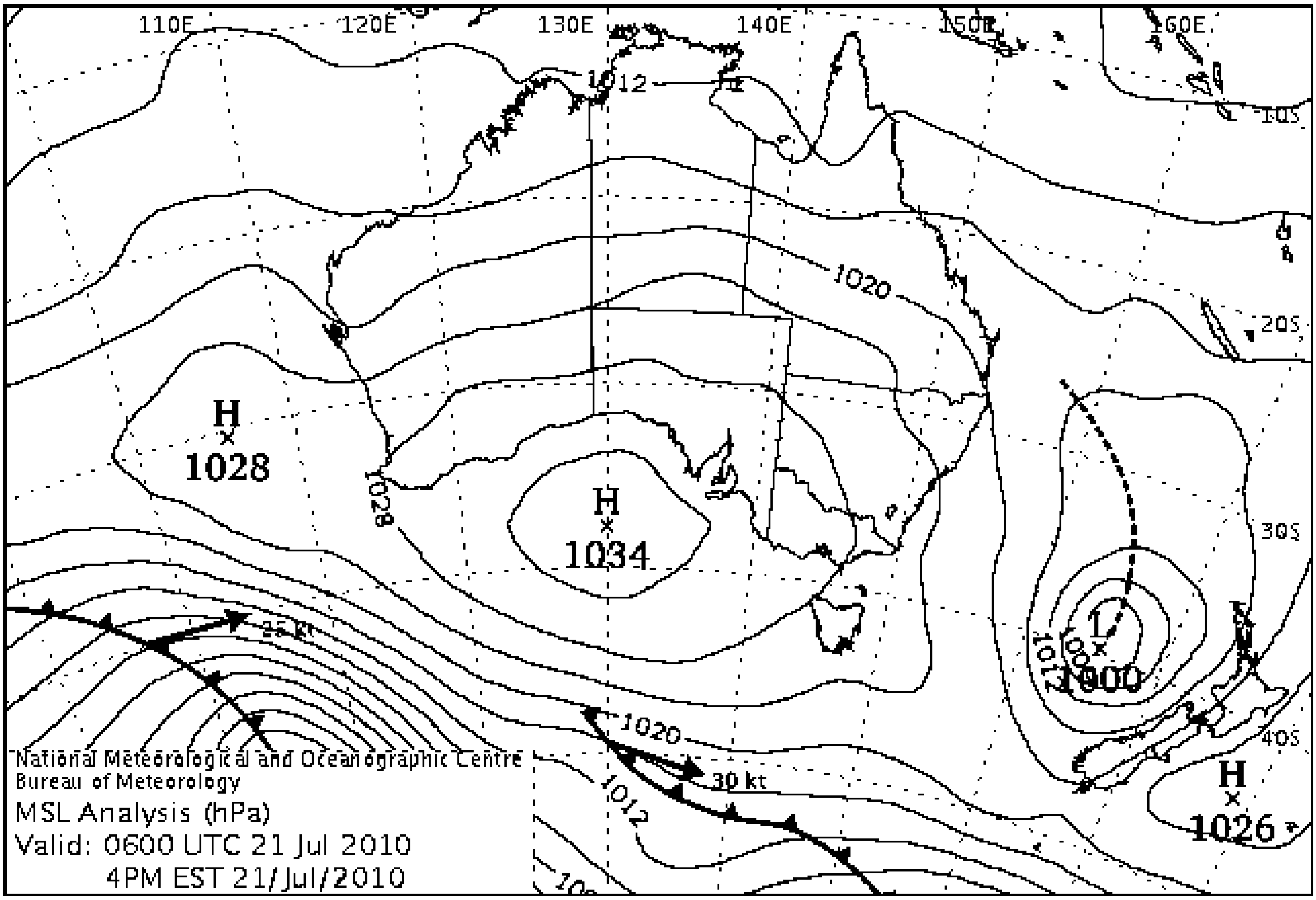
# Appendix E - Ashton Coal Weather Station Long Section



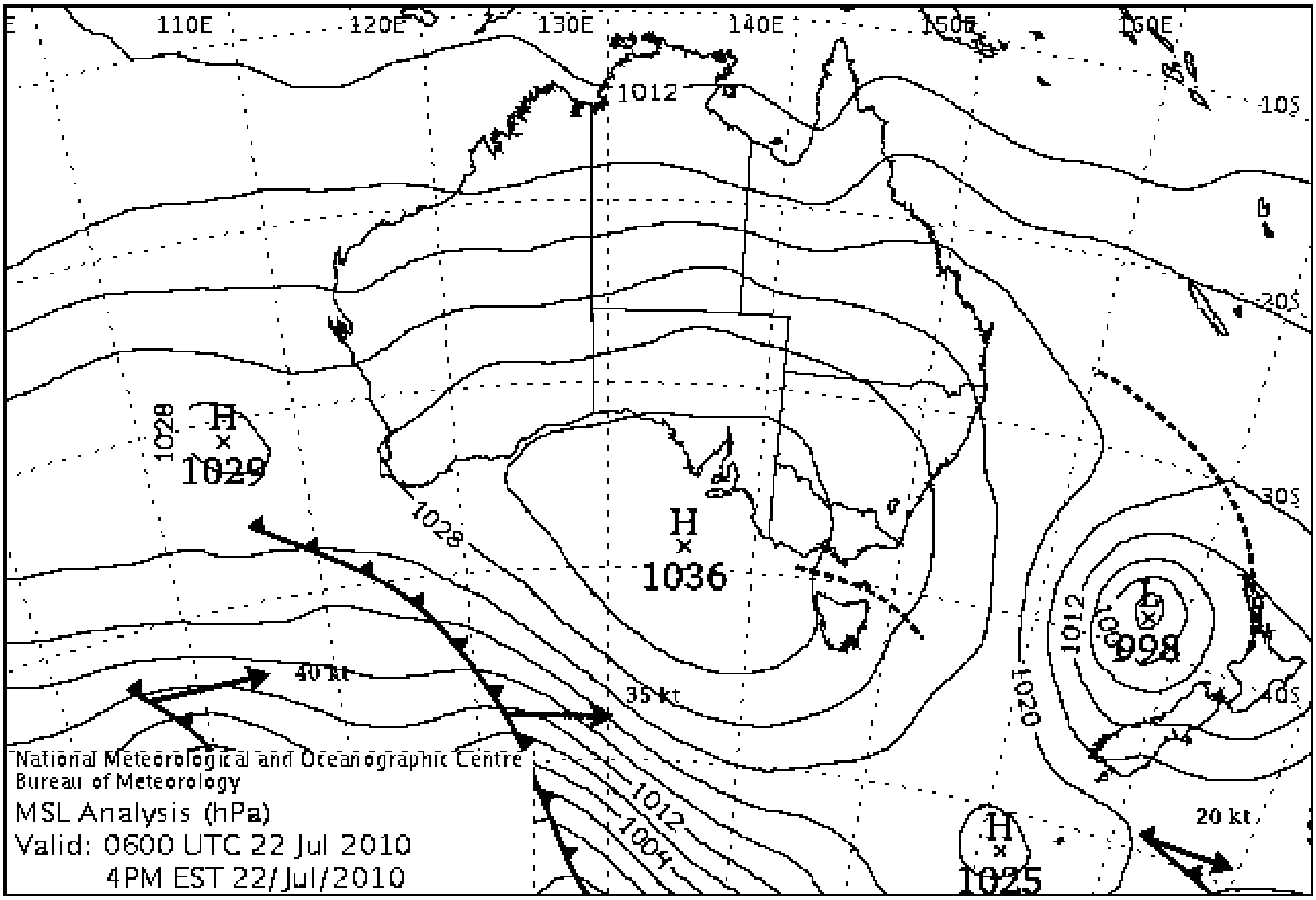
# Appendix F – Mean Sea Level Pressure Charts



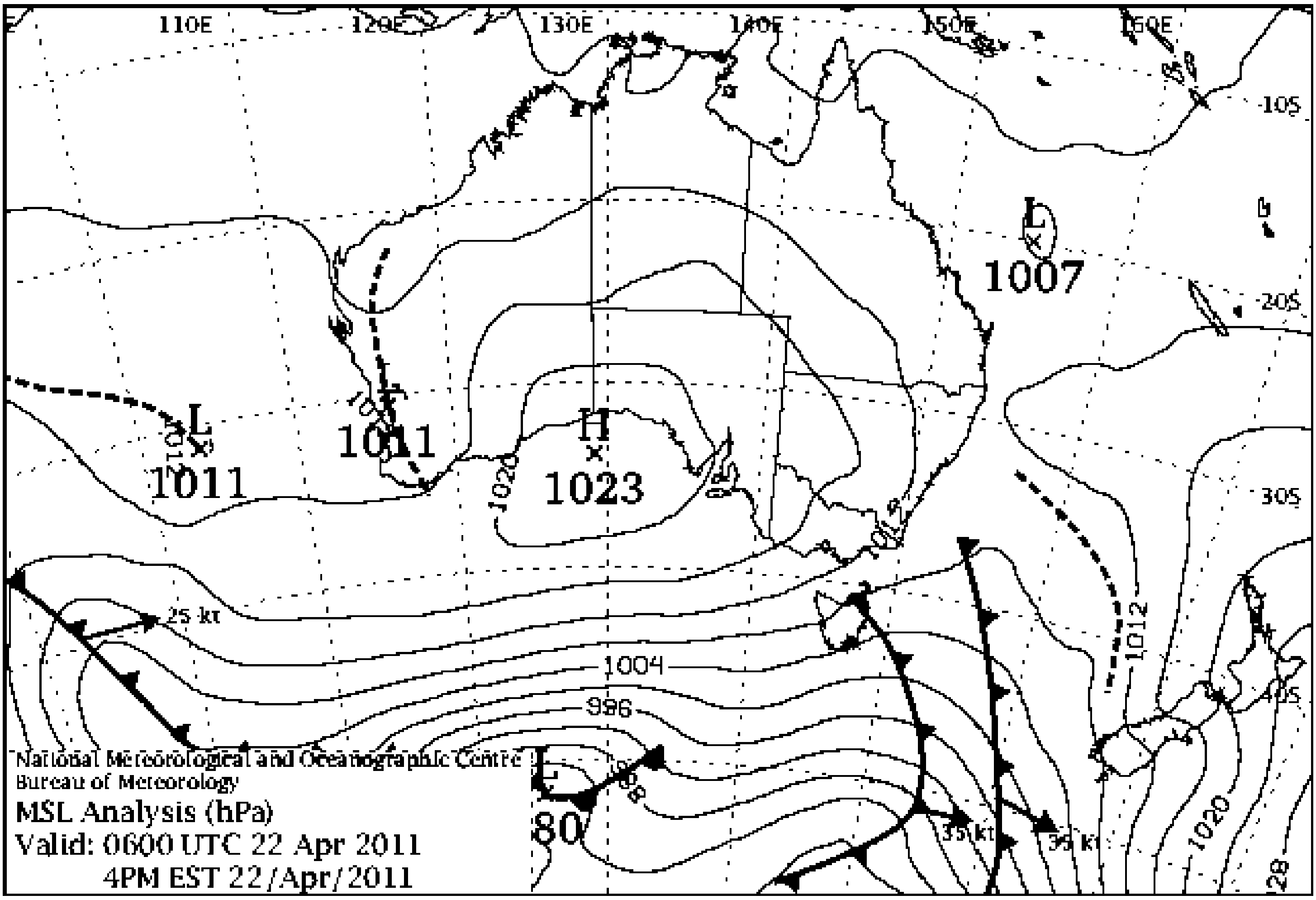



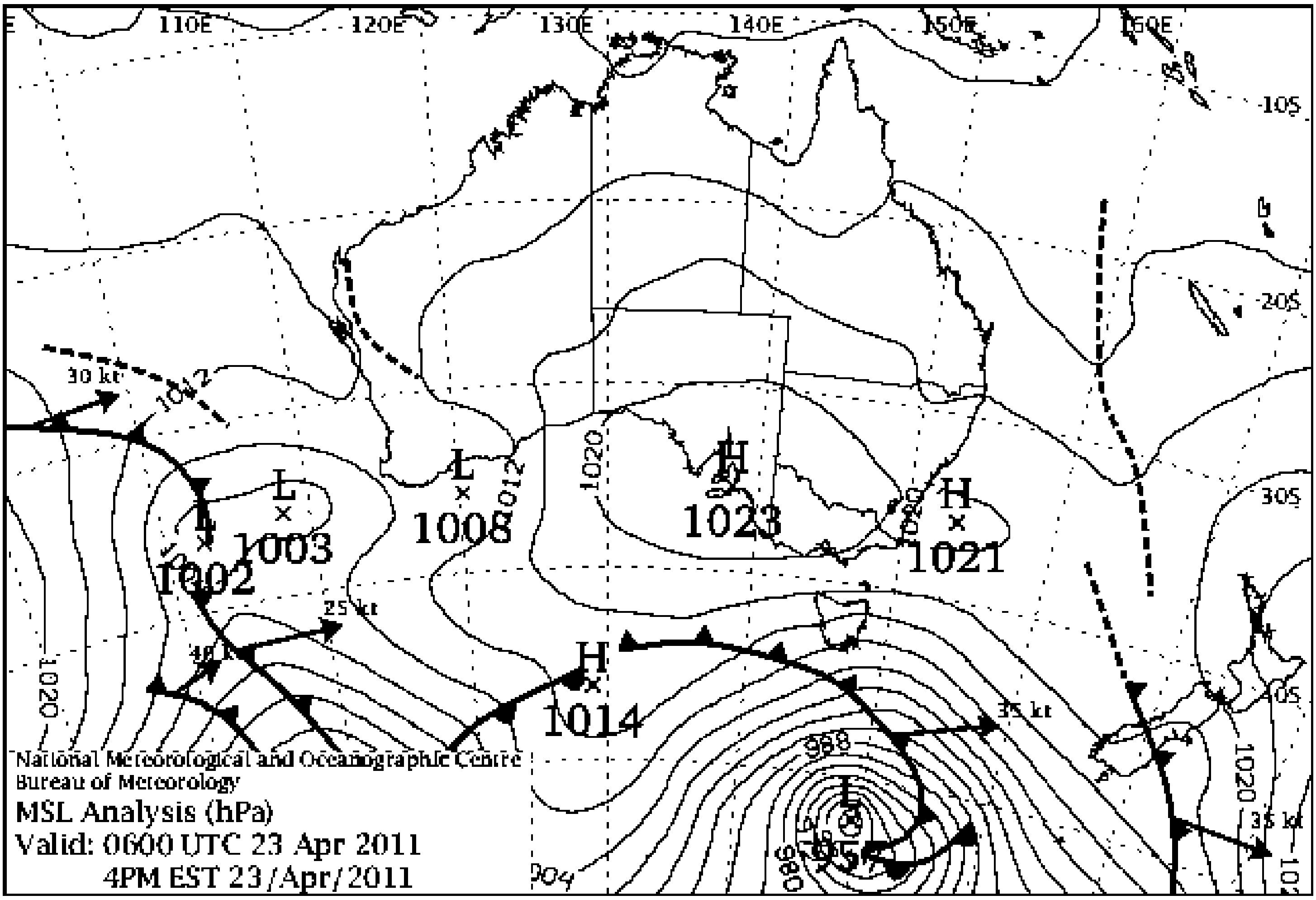


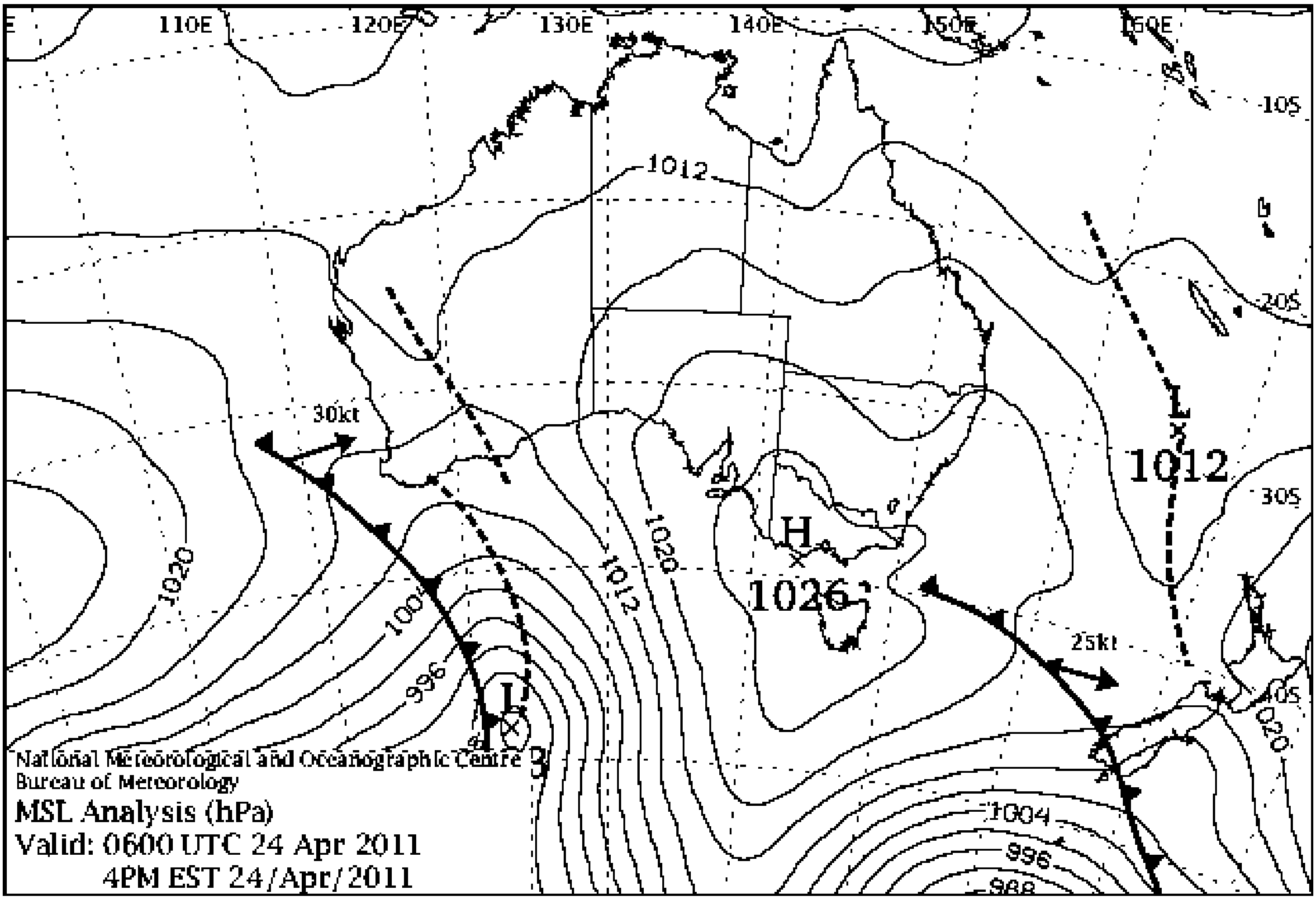
110E
120E
130E
140E
150E
160E
10S
20S
30S
40S
1012
1020
1028
1020
1012
H 1028
H 1034
L 1000
H 1026
25 kt
30 kt
National Meteorological and Oceanographic Centre
Bureau of Meteorology
MSL Analysis (hPa)
Valid: 0600 UTC 21 Jul 2010
4PM EST 21/Jul/2010

110E
120E
130E
140E
150E
160E
10S
20S
30S
40S
1012
1028
1028
1012
1004
1012
1020
H 1029
H 1036
L 998
H 1025
40 kt
35 kt
20 kt
National Meteorological and Oceanographic Centre
Bureau of Meteorology
MSL Analysis (hPa)
Valid: 0600 UTC 22 Jul 2010
4PM EST 22/Jul/2010


110E
120E
130E
140E
150E
160E
10S
20S
30S
40S
L
1007
L
1011
1011
H
1023
1020
1004
996
L
25 kt
35 kt
35 kt
1012
1020
National Meteorological and Oceanographic Centre
Bureau of Meteorology
MSL Analysis (hPa)
Valid: 0600 UTC 22 Apr 2011
4PM EST 22/Apr/2011


110E
120E
130E
140E
150E
160E
10S
20S
30S
40S
30 kt
1012
L
1003
1002
L
1008
1012
1020
H
1023
H
1021
H
1014
25 kt
40 kt
35 kt
35 kt
988
980
1020
National Meteorological and Oceanographic Centre
Bureau of Meteorology
MSL Analysis (hPa)
Valid: 0600 UTC 23 Apr 2011
4PM EST 23/Apr/2011


110E
120E
130E
140E
150E
160E
10S
20S
30S
40S
1012
1020
1026
1012
1004
996
988
30kt
25kt
H
L
National Meteorological and Oceanographic Centre
Bureau of Meteorology
MSL Analysis (hPa)
Valid: 0600 UTC 24 Apr 2011
4PM EST 24/Apr/2011

# Appendix G - 15 Minute Averages

**---19 / 07 / 2010 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:45 AM | 7:00 AM | 2.4 | | 2.7 | 8.3 | | | | | | | | |
| 7:00 AM | 7:15 AM | 2.5 | | 2.9 | 9.4 | | | | | | | | |
| 7:15 AM | 7:30 AM | 2.5 | | 3.2 | 9.0 | | | | | | | | |
| 7:30 AM | 7:45 AM | 3 | | 3.3 | 8.4 | | | | | | | | |
| 8:15 AM | 8:30 AM | 6.4 | | 6.3 | 7.9 | | | | | | | | |
| 8:30 AM | 8:45 AM | 6.5 | | 6.6 | 8.0 | | | | | | | | |
| 8:45 AM | 9:00 AM | 6.7 | | 7.7 | 8.1 | | | | | | | | |
| 9:00 AM | 9:15 AM | 7.3 | | 8.0 | 8.2 | | | | | | | | |
| 9:15 AM | 9:30 AM | 8.6 | | 8.1 | 8.5 | | | | | | | | |
| 9:30 AM | 9:45 AM | 9.7 | | 8.5 | 8.9 | | | | | | | | |
| 9:45 AM | 10:00 AM | 10.4 | | 9.2 | 9.0 | | | | | | | | |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4:30 PM | 4:45 PM | 14.5 | 14.3 | 14.1 | 14.2 | -0.30 | E | -0.14 | E | -2.11 | A | -0.40 | E |
| 4:45 PM | 5:00 PM | 13 | 13.7 | 14.0 | 14.1 | 1.11 | E | 0.41 | E | 8.94 | G | 0.49 | E |
| 5:00 PM | 5:15 PM | 9.8 | 12.9 | 13.9 | 14.2 | 4.48 | G | 1.43 | E | 38.84 | G | 1.97 | F |
| 5:15 PM | 5:30 PM | 9 | 12.5 | 13.9 | 14.3 | 5.39 | G | 2.02 | F | 43.34 | G | 2.79 | F |
| 5:30 PM | 5:45 PM | 8.3 | 12.3 | 13.9 | 14.2 | 6.00 | G | 2.04 | F | 50.56 | G | 3.16 | F |
| 5:45 PM | 6:00 PM | 8.3 | 12.2 | 13.8 | 14.3 | 6.08 | G | 2.27 | F | 48.83 | G | 3.21 | F |
| 6:00 PM | 6:15 PM | 8.3 | 12.0 | 13.2 | 13.8 | 5.65 | G | 2.05 | F | 46.07 | G | 2.46 | F |
| 6:15 PM | 6:30 PM | 7.9 | 10.1 | 13.1 | 13.5 | 5.74 | G | 3.82 | F | 27.36 | G | 5.93 | G |
| 6:30 PM | 6:45 PM | 7.8 | 10.0 | 12.6 | 13.3 | 5.66 | G | 3.73 | F | 27.32 | G | 5.25 | G |

**---20 / 07 / 2010 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:30 AM | 6:45 AM | 5.6 | 6.9 | 9.1 | 10.0 | 4.50 | G | 3.47 | F | 16.11 | G | 4.41 | G |
| 6:45 AM | 7:00 AM | 5.6 | 7.3 | 9.1 | 10.0 | 4.47 | G | 3.01 | F | 20.84 | G | 3.69 | F |
| 7:00 AM | 7:15 AM | 5.3 | 6.4 | 8.0 | 10.0 | 4.76 | G | 3.92 | F | 14.28 | G | 3.08 | F |
| 7:15 AM | 7:30 AM | 5.7 | 6.4 | 7.2 | 9.4 | 3.80 | F | 3.34 | F | 8.92 | G | 1.53 | F |
| 7:30 AM | 7:45 AM | 5.9 | 6.8 | 8.6 | 9.9 | 4.07 | G | 3.40 | F | 11.57 | G | 3.45 | F |
| 7:45 AM | 8:00 AM | 6.9 | 7.2 | 9.2 | 10.2 | 3.35 | F | 3.36 | F | 3.23 | G | 3.99 | F |
| 8:00 AM | 8:15 AM | 7.9 | 7.9 | 9.0 | 10.2 | 2.30 | F | 2.49 | F | 0.14 | E | 2.14 | F |
| 8:15 AM | 8:30 AM | 9.2 | 8.6 | 8.8 | 10.2 | 1.05 | E | 1.76 | F | -6.92 | A | 0.39 | E |
| 8:30 AM | 8:45 AM | 11.4 | 9.9 | 9.3 | 10.4 | -1.05 | D | 0.53 | E | -18.84 | A | -1.24 | D |
| 8:45 AM | 9:00 AM | 12.5 | 11.3 | 9.8 | 10.4 | -2.11 | A | -0.94 | D | -15.24 | A | -2.97 | A |
| 9:00 AM | 9:15 AM | 13.1 | 11.6 | 9.9 | 10.6 | -2.60 | A | -1.12 | D | -19.26 | A | -3.26 | A |
| 9:15 AM | 9:30 AM | 13.4 | 11.9 | 10.2 | 10.8 | -2.69 | A | -1.31 | D | -18.24 | A | -3.49 | A |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:30 PM | 12:45 PM | 16.2 | 15.3 | 13.8 | 13.7 | -2.57 | A | -1.84 | B | -10.88 | A | -3.02 | A |
| 12:45 PM | 1:00 PM | 18.1 | 15.5 | | | | | | | | | | |
| 1:00 PM | 1:15 PM | 17.8 | 15.2 | 13.9 | 13.8 | -4.10 | A | -1.61 | C | -32.09 | A | -2.59 | A |
| 1:15 PM | 1:30 PM | 17 | 15.3 | 14.2 | 14.1 | -2.97 | A | -1.32 | D | -21.56 | A | -2.13 | A |
| 1:30 PM | 1:45 PM | 16.6 | 15.2 | 14.3 | 14.2 | -2.45 | A | -1.16 | D | -16.91 | A | -1.98 | A |
| 1:45 PM | 2:00 PM | 15.9 | 15.3 | 14.3 | 14.2 | -1.75 | B | -1.21 | D | -7.78 | A | -1.93 | A |
| 2:00 PM | 2:15 PM | 16 | 15.3 | 14.3 | 14.2 | -1.80 | B | -1.18 | D | -8.80 | A | -1.96 | A |
| 2:15 PM | 2:30 PM | 15.9 | 15.1 | 14.3 | 14.2 | -1.78 | B | -1.09 | D | -9.46 | A | -1.78 | B |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4:00 PM | 4:15 PM | 15.2 | 14.9 | 14.5 | 14.5 | -0.68 | D | -0.38 | E | -4.01 | A | -0.72 | D |
| 4:15 PM | 4:30 PM | 14.6 | 14.7 | 14.4 | 14.4 | -0.15 | E | -0.30 | E | 1.45 | E | -0.54 | D |
| 4:30 PM | 4:45 PM | 13.9 | 14.6 | 14.3 | 14.4 | 0.53 | E | -0.16 | E | 8.22 | G | -0.46 | E |
| 4:45 PM | 5:00 PM | 13.3 | 14.3 | 14.4 | 14.4 | 1.12 | E | 0.16 | E | 11.91 | G | 0.26 | E |

**---21 / 07 / 2010 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:30 AM | 6:45 AM | 4.6 | 5.9 | 6.7 | 9.3 | 4.75 | G | 3.74 | F | 16.10 | G | 1.64 | F |
| 6:45 AM | 7:00 AM | 4.7 | 5.9 | 6.9 | 8.8 | 4.15 | G | 3.17 | F | 15.12 | G | 2.06 | F |
| 7:00 AM | 7:15 AM | 4.8 | 6.3 | 7.6 | 8.4 | 3.64 | F | 2.28 | F | 18.96 | G | 2.62 | F |
| 7:15 AM | 7:30 AM | 4.7 | 5.9 | 7.6 | 9.0 | 4.41 | G | 3.49 | F | 14.82 | G | 3.45 | F |
| 7:30 AM | 7:45 AM | 6.1 | 5.9 | 7.4 | 8.4 | 2.30 | F | 2.72 | F | -2.42 | A | 2.94 | F |
| 7:45 AM | 8:00 AM | 7 | 6.6 | 7.6 | 8.7 | 1.74 | F | 2.35 | F | -5.09 | A | 2.04 | F |
| 8:00 AM | 8:15 AM | 8.8 | 8.0 | 8.0 | 9.1 | 0.27 | E | 1.21 | E | -10.34 | A | 0.14 | E |
| 8:15 AM | 8:30 AM | 9.1 | 8.4 | 8.0 | 8.6 | -0.46 | E | 0.23 | E | -8.31 | A | -0.93 | D |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4:30 PM | 4:45 PM | 12.5 | 12.8 | 12.3 | 12.3 | -0.17 | E | -0.47 | E | 3.21 | F | -0.91 | D |
| 4:45 PM | 5:00 PM | 12.1 | 12.5 | 12.1 | 12.3 | 0.21 | E | -0.18 | E | 4.62 | G | -0.64 | D |
| 5:00 PM | 5:15 PM | 11.6 | 12.3 | 12.0 | 12.1 | 0.50 | E | -0.20 | E | 8.40 | G | -0.58 | D |
| 5:15 PM | 5:30 PM | 10.6 | 12.1 | 12.0 | 12.0 | 1.46 | E | -0.13 | E | 19.36 | G | -0.29 | E |
| 5:30 PM | 5:45 PM | 10.5 | 12.1 | 12.0 | 12.1 | 1.59 | F | -0.01 | E | 19.60 | G | -0.13 | E |
| 5:45 PM | 6:00 PM | 9.4 | 11.6 | 11.9 | 12.1 | 2.74 | F | 0.49 | E | 28.11 | G | 0.42 | E |
| 6:00 PM | 6:15 PM | 8.7 | 11.4 | 11.8 | 12.2 | 3.54 | F | 0.87 | E | 33.50 | G | 0.82 | E |
| 6:15 PM | 6:30 PM | 8.5 | 11.6 | 11.6 | 12.1 | 3.62 | F | 0.54 | E | 38.31 | G | 0.13 | E |
| 6:30 PM | 6:45 PM | 8.6 | 11.1 | 11.6 | 12.0 | 3.46 | F | 0.95 | E | 31.70 | G | 0.87 | E |
| 6:45 PM | 7:00 PM | 7.9 | 10.1 | 11.3 | 11.9 | 4.05 | G | 1.93 | E | 27.90 | G | 2.43 | F |

**---21 / 07 / 2010 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:15 AM | 6:30 AM | 0.1 | 1.8 | 4.8 | 7.1 | 7.16 | G | 5.94 | G | 20.81 | G | 5.98 | G |
| 6:30 AM | 6:45 AM | 0.6 | 3.2 | 5.9 | 7.1 | 6.62 | G | 4.36 | G | 32.04 | G | 5.45 | G |
| 6:45 AM | 7:00 AM | 0.1 | 3.1 | 5.6 | 6.9 | 6.97 | G | 4.20 | G | 38.07 | G | 4.99 | G |
| 7:00 AM | 7:15 AM | 0.2 | | | | | | | | | | | |
| 7:15 AM | 7:30 AM | 0.5 | 1.8 | 5.7 | 6.9 | 6.53 | G | 5.64 | G | 16.48 | G | 7.84 | G |
| 7:30 AM | 7:45 AM | 0.7 | 1.6 | 5.8 | 7.0 | 6.44 | G | 6.01 | G | 11.32 | G | 8.48 | G |
| 7:45 AM | 8:00 AM | 2.5 | 2.5 | 5.5 | 6.7 | 4.27 | G | 4.66 | G | -0.11 | E | 5.95 | G |
| 8:00 AM | 8:15 AM | 4.2 | 4.5 | 5.8 | 6.7 | 2.54 | F | 2.48 | F | 3.24 | F | 2.60 | F |
| 8:15 AM | 8:30 AM | 6.1 | 5.7 | 6.1 | 6.9 | 0.81 | E | 1.36 | E | -5.33 | A | 0.93 | E |
| 8:30 AM | 8:45 AM | 8.2 | 7.2 | 6.6 | 7.4 | -0.78 | D | 0.32 | E | -13.08 | A | -1.07 | D |
| 8:45 AM | 9:00 AM | 9.2 | 7.9 | 7.1 | 7.4 | -1.89 | B | -0.60 | D | -16.38 | A | -1.53 | C |

**---22 / 04 / 2011 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:30 AM | 6:45 AM | 11.0 | 10.7 | 14.2 | 15.0 | 4.06 | G | 4.77 | G | -3.93 | A | 6.97 | G |
| 6:45 AM | 7:00 AM | 10.5 | 10.7 | 14.4 | 14.9 | 4.47 | G | 4.62 | G | 2.72 | F | 7.35 | G |
| 7:00 AM | 7:15 AM | 12.5 | 13.7 | 14.6 | 14.9 | 2.48 | F | 1.41 | E | 14.47 | F | 1.91 | F |
| 7:15 AM | 7:30 AM | 13.6 | 14.3 | 14.6 | 14.7 | 1.08 | E | 0.36 | E | 9.18 | F | 0.48 | E |
| 7:30 AM | 7:45 AM | 14.5 | 14.4 | 14.6 | 15.0 | 0.47 | E | 0.66 | E | -1.77 | B | 0.57 | E |
| 7:45 AM | 8:00 AM | 15.8 | 14.7 | 14.5 | 14.4 | -1.45 | D | -0.30 | E | -14.32 | A | -0.21 | E |
| 8:00 AM | 8:15 AM | 16.5 | 15.1 | 14.9 | 14.6 | -1.97 | A | -0.59 | D | -17.50 | A | -0.48 | E |
| 8:15 AM | 8:30 AM | 18.4 | 15.9 | 15.6 | 15.4 | -3.09 | A | -0.56 | D | -31.63 | A | -0.47 | E |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 PM | 12:15 PM | 26.5 | 24.8 | 24.7 | 24.0 | -2.55 | A | -0.84 | D | -21.70 | A | -0.12 | E |
| 12:15 PM | 12:30 PM | 27.2 | 25.0 | 25.0 | 24.3 | -2.96 | A | -0.79 | D | -27.35 | A | -0.02 | E |
| 12:30 PM | 12:45 PM | 27.1 | 24.8 | 24.8 | 24.2 | -3.01 | A | -0.75 | D | -28.41 | A | 0.01 | E |
| 12:45 PM | 01:00 PM | 26.7 | 25.0 | 25.1 | 24.3 | -2.42 | A | -0.76 | D | -21.08 | A | 0.14 | E |

*high winds forced an end to data collection*

## ---23 / 04 / 2011 ---

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:15 AM | 06:30 AM | 6.8 | 7.6 | 11.3 | 12.4 | 5.66 | G | 5.31 | G | 9.61 | G | 7.40 | G |
| 06:30 AM | 06:45 AM | 7.2 | 7.9 | 11.8 | 12.4 | 5.33 | G | 4.99 | G | 9.15 | G | 7.70 | G |
| 06:45 AM | 07:00 AM | 7.5 | 7.9 | 11.8 | 12.9 | 5.48 | G | 5.55 | G | 4.74 | G | 7.88 | G |
| 07:00 AM | 07:15 AM | 9.0 | 9.2 | 11.9 | 13.1 | 4.18 | G | 4.31 | G | 2.67 | F | 5.45 | G |
| 07:15 AM | 07:30 AM | 10.2 | 9.9 | 11.6 | 13.0 | 2.90 | F | 3.54 | F | -4.28 | A | 3.52 | F |
| 07:30 AM | 07:45 AM | 11.8 | 11.0 | 11.8 | 12.9 | 1.16 | E | 2.18 | F | -10.33 | A | 1.68 | F |
| 07:45 AM | 08:00 AM | 12.5 | 12.1 | 12.4 | 13.2 | 0.70 | E | 1.22 | E | -5.21 | A | 0.67 | E |
| 08:00 AM | 08:15 AM | 14.6 | 13.0 | 13.3 | 13.4 | -1.20 | D | 0.49 | E | -20.18 | A | 0.61 | E |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 PM | 12:15 PM | 21.5 | 20.9 | 20.0 | 19.2 | -2.37 | A | -1.90 | A | -7.62 | A | -1.76 | B |
| 12:15 PM | 12:30 PM | 21.8 | 21.1 | 20.2 | 19.4 | -2.43 | A | -1.86 | B | -8.86 | A | -1.74 | B |
| 12:30 PM | 12:45 PM | 22.4 | 21.5 | 20.6 | 19.7 | -2.74 | A | -2.02 | A | -10.88 | A | -1.95 | A |
| 12:45 PM | 01:00 PM | 22.9 | 21.8 | 20.9 | 20.1 | -2.89 | A | -1.97 | A | -13.16 | A | -1.94 | A |
| 01:00 PM | 01:15 PM | 23.1 | 21.8 | 20.9 | 20.2 | -2.95 | A | -1.82 | B | -15.66 | A | -1.97 | A |
| 01:15 PM | 01:30 PM | 23.0 | 22.0 | 21.1 | 20.4 | -2.69 | A | -1.82 | B | -12.41 | A | -1.81 | B |
| 01:30 PM | 01:45 PM | 23.6 | 22.3 | 21.3 | 20.6 | -3.03 | A | -1.82 | B | -16.63 | A | -1.90 | A |
| 01:45 PM | 02:00 PM | 23.4 | 22.5 | 21.5 | 20.8 | -2.68 | A | -1.88 | B | -11.65 | A | -1.90 | A |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05:15 PM | 05:30 PM | 20.4 | 19.7 | 19.7 | 19.2 | -1.18 | D | -0.50 | D | -8.89 | A | -0.07 | E |
| 05:30 PM | 05:45 PM | 19.0 | 18.9 | 19.0 | 18.7 | -0.29 | E | -0.26 | E | -0.68 | D | 0.15 | E |
| 05:45 PM | 06:00 PM | 18.7 | 18.5 | 18.6 | 18.3 | -0.42 | E | -0.21 | E | -2.79 | A | 0.19 | E |
| 06:00 PM | 06:15 PM | 18.0 | 18.0 | 18.1 | 17.9 | -0.14 | E | -0.10 | E | -0.61 | D | 0.38 | E |
| 06:15 PM | 06:30 PM | 17.9 | 17.6 | 17.8 | 17.5 | -0.39 | E | -0.09 | E | -3.75 | A | 0.34 | E |

*high winds forced an end to data collection*

## ---24 / 04 / 2011 ---

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:00 AM | 06:15 AM | 16.6 | 16.1 | 15.9 | 15.4 | -1.21 | D | -0.74 | D | -6.51 | A | -0.28 | E |
| 06:15 AM | 06:30 AM | 16.5 | 16.1 | 15.9 | 15.4 | -1.16 | D | -0.81 | D | -5.03 | A | -0.32 | E |
| 06:30 AM | 06:45 AM | 16.5 | 16.1 | 15.9 | 15.5 | -1.07 | D | -0.74 | D | -4.78 | A | -0.39 | E |
| 06:45 AM | 07:00 AM | 16.6 | 16.1 | 15.9 | 15.5 | -1.13 | D | -0.71 | D | -5.90 | A | -0.40 | E |
| 07:00 AM | 07:15 AM | 16.6 | 16.3 | 16.0 | 15.6 | -1.02 | D | -0.72 | D | -4.37 | A | -0.52 | D |
| 07:15 AM | 07:30 AM | 16.7 | 16.4 | 16.0 | 15.5 | -1.23 | D | -0.95 | D | -4.33 | A | -0.69 | D |
| 07:30 AM | 07:45 AM | 17.0 | 16.6 | 16.1 | 15.5 | -1.54 | D | -1.20 | D | -5.37 | A | -0.91 | D |
| 07:45 AM | 08:00 AM | 17.2 | 16.7 | 16.2 | 15.6 | -1.68 | D | -1.28 | D | -6.13 | A | -1.00 | D |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 PM | 12:15 PM | 21.6 | 20.9 | 20.2 | 19.5 | -2.16 | A | -1.58 | C | -8.62 | A | -1.50 | C |
| 12:15 PM | 12:30 PM | 22.0 | 21.2 | 20.4 | 19.7 | -2.37 | A | -1.68 | C | -10.18 | A | -1.56 | C |
| 12:30 PM | 12:45 PM | 22.0 | 21.5 | 20.6 | 20.0 | -2.06 | A | -1.65 | C | -6.68 | A | -1.73 | B |
| 12:45 PM | 01:00 PM | 23.0 | 21.9 | 21.1 | 20.5 | -2.60 | A | -1.57 | C | -14.22 | A | -1.52 | C |
| 01:00 PM | 01:15 PM | 23.3 | 22.3 | 21.4 | 20.7 | -2.64 | A | -1.75 | B | -12.67 | A | -1.81 | B |
| 01:15 PM | 01:30 PM | 23.0 | 21.9 | 21.4 | 20.7 | -2.33 | A | -1.37 | D | -13.13 | A | -1.11 | D |
| 01:30 PM | 01:45 PM | 24.0 | 22.7 | 21.8 | 21.1 | -2.94 | A | -1.74 | B | -16.44 | A | -1.76 | B |
| 01:45 PM | 02:00 PM | 23.8 | 22.9 | 22.1 | 21.4 | -2.47 | A | -1.72 | B | -11.00 | A | -1.74 | B |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04:00 PM | 04:15 PM | 24.1 | 23.7 | 22.5 | 22.5 | -1.68 | C | -1.44 | D | -4.40 | A | -2.58 | A |
| 04:15 PM | 04:30 PM | 23.9 | 23.5 | 22.3 | 22.3 | -1.64 | C | -1.31 | D | -5.31 | A | -2.38 | A |
| 04:30 PM | 04:45 PM | 23.2 | 22.9 | 21.9 | 21.9 | -1.28 | D | -1.10 | D | -3.31 | A | -1.98 | A |
| 04:45 PM | 05:00 PM | 22.5 | 22.6 | 21.8 | 21.8 | -0.73 | D | -0.90 | D | 1.23 | E | -1.62 | C |
| 05:00 PM | 05:15 PM | 22.3 | 22.2 | 21.5 | 21.5 | -0.85 | D | -0.80 | D | -1.34 | D | -1.43 | D |
| 05:15 PM | 05:30 PM | 21.9 | 21.8 | 21.2 | 21.2 | -0.75 | D | -0.69 | D | -1.43 | D | -1.25 | D |
| 05:30 PM | 05:45 PM | 21.4 | 21.4 | 20.8 | 20.9 | -0.56 | D | -0.57 | D | -0.37 | E | -1.06 | D |
| 05:45 PM | 06:00 PM | 21.0 | 21.0 | 20.5 | 20.5 | -0.48 | E | -0.50 | D | -0.35 | E | -0.91 | D |

# Appendix H - Hourly Averages

## ---19 / 07 / 2010 ---

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:45 AM | 7:45 AM | | | | | | | | | | | | |
| 8:15 AM | 9:00 AM | | | | | | | | | | | | |
| 9:00 AM | 10:00 AM | | | | | | | | | | | | |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04:30 PM | 05:30 PM | 11.6 | 13.3 | 14.0 | 14.2 | 2.67 | F | 0.95 | E | 22.05 | G | 1.25 | E |
| 5:30 PM | 6:30 PM | 8.2 | 11.6 | 13.5 | 13.9 | 5.86 | G | 2.56 | G | 43.07 | G | 3.70 | F |

## ---20 / 07 / 2010 ---

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:30 AM | 07:30 AM | 5.6 | 6.7 | 8.3 | 9.8 | 4.37 | G | 3.44 | F | 14.82 | G | 3.08 | F |
| 07:30 AM | 08:30 AM | 7.5 | 7.6 | 8.9 | 10.1 | 2.69 | F | 2.74 | F | 2.12 | F | 2.47 | F |
| 08:30 AM | 09:30 AM | 12.6 | 11.2 | 9.8 | 10.5 | -2.11 | A | -0.71 | D | -17.87 | A | -2.73 | A |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:30 PM | 01:30 PM | 17.3 | 15.3 | - | - | | | | | | | | |
| 01:30 PM | 02:30 PM | 16.1 | 15.2 | 14.3 | 14.2 | -1.94 | A | -1.16 | D | -10.73 | A | -1.91 | A |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04:00 PM | 05:00 PM | 14.3 | 14.6 | 14.4 | 14.4 | 0.20 | E | -0.19 | E | 4.62 | G | -0.40 | E |

## ---21 / 07 / 2010 ---

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:30 AM | 07:30 AM | 4.7 | 6.0 | 7.2 | 8.8 | 4.23 | G | 3.16 | F | 16.24 | G | 2.46 | F |
| 07:30 AM | 08:30 AM | 7.8 | 7.2 | 7.7 | 8.7 | 0.97 | E | 1.66 | F | -6.76 | A | 1.08 | E |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04:30 PM | 05:30 PM | 11.7 | 12.4 | 12.1 | 12.2 | 0.51 | E | -0.24 | E | 8.96 | G | -0.61 | D |
| 05:30 PM | 06:30 PM | 9.3 | 11.7 | 11.8 | 12.1 | 2.87 | F | 0.47 | E | 29.89 | G | 0.31 | E |

**---22 / 07 / 2010 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:15 AM | 07:00 AM | 0.3 | 2.7 | 5.4 | 7.0 | 6.92 | G | 4.81 | G | 30.63 | G | 5.44 | G |
| 07:00 AM | 08:00 AM | 1.0 | 6.4 | 5.7 | 6.8 | 5.99 | G | 0.55 | E | 67.25 | G | -1.32 | G |
| 08:00 AM | 09:00 AM | 6.9 | 6.4 | 6.4 | 7.1 | 0.19 | E | 0.84 | E | -7.13 | A | 0.11 | E |

**---22 / 04 / 2011 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 6:30 AM | 7:30 AM | 11.9 | 12.4 | 14.4 | 14.9 | 3.01 | F | 2.73 | F | 6.17 | G | 4.11 | G |
| 7:30 AM | 8:30 AM | 16.3 | 15.0 | 14.9 | 14.8 | -1.52 | C | -0.22 | E | -16.18 | A | -0.18 | E |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 PM | 01:00 PM | 26.9 | 24.9 | 24.9 | 24.2 | -2.75 | A | -0.79 | D | -24.77 | A | -0.01 | E |

*high winds forced an end to data collection*

**---23 / 04 / 2011 ---**

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:15 AM | 07:15 AM | 7.6 | 8.2 | 11.7 | 12.7 | 5.20 | G | 5.05 | G | 6.88 | G | 7.13 | G |
| 07:15 AM | 08:15 AM | 12.3 | 11.5 | 12.3 | 13.1 | 0.86 | E | 1.85 | F | -10.36 | A | 1.64 | F |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 PM | 01:00 PM | 22.2 | 21.3 | 20.4 | 19.6 | -2.66 | A | -1.94 | A | -10.73 | A | -1.84 | B |
| 01:00 PM | 02:00 PM | 23.3 | 22.2 | 21.2 | 20.5 | -2.87 | A | -1.85 | B | -14.35 | A | -1.91 | A |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05:30 PM | 06:30 PM | 18.4 | 18.2 | 18.4 | 18.1 | -0.31 | E | -0.16 | E | -1.96 | A | 0.31 | E |

*high winds forced an end to data collection*

## ---24 / 04 / 2011 ---

***Morning***

| | | Average Temperature (°C) | | | | Lapse Rate (°C) | | | | Extrapolation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Starting*** | ***Ending*** | ***2m*** | ***10m*** | ***60m*** | ***100m*** | ***2-100m*** | ***Class*** | ***10-100m*** | ***Class*** | ***2-10m*** | ***Class*** | ***10-60m*** | ***Class*** |
| 06:00 AM | 07:00 AM | 16.6 | 16.1 | 15.9 | 15.4 | -1.19 | D | -0.75 | D | -6.17 | A | -0.35 | E |
| 07:00 AM | 08:00 AM | 16.9 | 16.5 | 16.1 | 15.5 | -1.39 | D | -1.05 | D | -5.27 | A | -0.78 | E |

***Midday***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 PM | 01:00 PM | 22.2 | 21.4 | 20.6 | 19.9 | -2.35 | A | -1.62 | C | -10.55 | A | -1.60 | C |
| 01:00 PM | 02:00 PM | 23.5 | 22.5 | 21.7 | 21.0 | -2.58 | A | -1.65 | C | -13.03 | A | -1.60 | C |

***Evening***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04:00 PM | 05:00 PM | 23.4 | 23.2 | 22.1 | 22.1 | -1.32 | D | -1.20 | D | -2.65 | A | -2.14 | A |
| 05:00 PM | 06:00 PM | 21.7 | 21.6 | 21.0 | 21.0 | -0.70 | D | -0.63 | D | -1.58 | C | -1.13 | D |