Meteorological Report for the Dalton Power Project, NSW

Determination of the occurrence and frequency of stability category temperature inversions

Date: 24 April 2017

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Document Revision History

Date	Version	Author	Reviewer	Comment
12/8/13	1.0	SY		Analysis performed on 5 months available data
16/8/13	1.1	SY		Revised to only include met conditions
6/10/13	1.2	SY		Updated with complete winter dataset
11/10/13	1.3	SY		Updated to include modelling of conditions specified in F10 of Project Approval conditions
14/10/13	1.4	SY		Updated to included dataset from February 2013 (this is the complete dataset)
15/10/13	1.5	SY	NC	Rearranged F10 conditions section, added F10 statistics, reviewed
29/10/13	1.6	SY		Dataset arranging, final check
4/2/14	1.7	SY/NC	JG (URS)	Comments incorporated.
24/4/17	1.8	DR	NB	Additional data added to the statistics

Executive Summary

Sections C41-C45 of the Project Approval granted for the Dalton Power Project (ref: MP10_0035 dated 19th July 2012), proposed by AGL Energy Ltd (AGL), outlined the requirement to determine the occurrence and frequency of stability category temperature inversions at the site. The outcomes of this are:

In accordance with condition C41 of the Project Approval AGL established a meteorological station on the site prior to 16th August 2012.

In accordance with condition C42 the weather parameters have been monitored. Data from 3rd February 2013 to 15th October 2014 (approximately 21 months of data) have been retrieved.

In accordance with conditions C43 and C44 of the Project Approval and the *NSW Industrial Noise Policy (2000)* analysis was performed using the sigma-theta method for data obtained. Class F and G stability conditions were identified to occur for 81.33% of winter night monitoring periods at the Project site. In accordance with the *INP* criterion, this indicates that temperature inversions are significant features warranting further assessment.

In accordance with condition C45 the type and frequency of temperature inversion conditions have been determined. The findings are:

› Category F and G inversions occur for 81.33% of the winter night dataset
› Category F and G inversions occur for 79.30% of the complete night dataset
› Category A occurs for 84.59% of the complete daytime dataset
› Category F and G inversions occur for 46.26% of the complete dataset (day and night)

1. Introduction

1.1. Legislative Context

Chapter 12 of the Environmental Assessment (EA) for AGL Energy Ltd's (AGL's) proposed Dalton Power Project assessed the potential noise impacts of the project during the construction and operations phase. As the proposal is for a gas fired peaking power plant estimated to operate for 5-15% of the year, night-time operations are possible, meaning that night-time noise impacts on nearby residences were considered.

Part of the modelling of night-time operations involves the consideration of meteorological conditions, specifically temperature inversions, in accordance with the *NSW Industrial Noise Policy (2000) Appendix A3*, which states:

> "Where F or G class inversions, or a combination of both, are predicted to occur for at least 30% of the total night-time in winter, this is considered to be significant and warrants assessment."

In response to this, the requirements of the Project Approval (sections C41-C45) detail the need for the proponent (AGL) to install and maintain a meteorological monitoring station on the site with a sufficient variety of data types to determine the prevalence of stability category inversions.[1]

Relevant to this report, the Project Approval state:

> C43. The Proponent shall use the meteorological data collected on site to determine the occurrence and frequency of stability category temperature inversions prevailing at the Project site and whether they occur for a significant period of time.
>
> C44. Stability category temperature inversion conditions (stability category) are to be determined in accordance with methods set out in the *NSW Industrial Noise Policy (Environment Protection Authority, 2000)*
>
> C45. After a period of 12 months of meteorological monitoring, the Proponent shall forward to the Director-General a report describing the type and frequency of temperature inversion conditions prevailing at the site. The report shall be made available on the dedicated website for the project within 1 month of it being forwarded to the Director-General.

AGL established a meteorological monitoring station on the project site that was commissioned on 16th August 2012. Unfortunately, the data from 16th August 2012 to 2nd February 2013 were unable to be retrieved. Data from 3rd February 2013 to 15th October 2014 (approximately 21 months of data) have therefore been used.

Table 1: Measurement site

Station	Designation	Location	Location description
Meteorological station	AGL-DT80	149.1975E 34.6882S	Site of the proposed Dalton Power Project

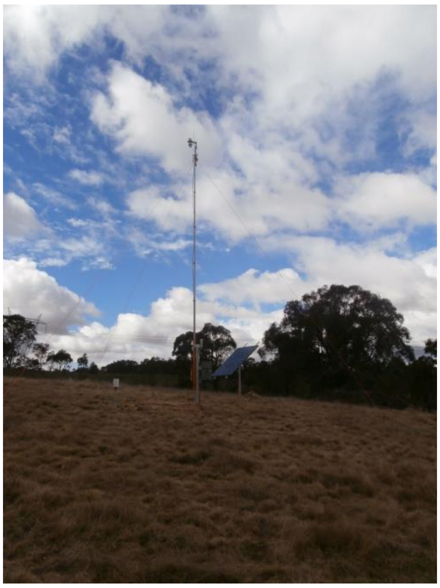


Figure 1: AGL-DT80 near Dalton, NSW

1.2. Stability Category Temperature Inversions

Appendix G of the EA, used in the prediction of the noise impacts of the Dalton Power Project, entailed noise modelling using acoustic computer modelling. Section 5.2 noted that:

> "Adverse meteorological conditions have the potential to increase noise levels at a receptor. Such phenomena generally occur during temperature inversions and where there is a wind gradient with wind direction from the source to the receptor. It is known that these meteorological effects typically increase noise levels by 5 to 10 dB, and even higher than 10 dB in extreme conditions."[2]

In this case, a temperature inversion is an "adverse meteorological condition" in which the air temperature increases with height above ground. This is opposed to normal conditions, where reflected solar radiation from the earth generally heats lower air, leading to a steady drop in average temperature with increasing altitude. Temperature inversions are caused by a range of meteorological effects, including the rapid cooling of the ground at nightfall in winter lowering the temperature of the air at low altitude. The combination of a temperature inversion and very stable conditions (low speed and steady wind) can lead to the formation of stratified packets of air, which can affect both the dispersal of pollutants and the propagation of noise.

A generally accepted measurement of the degree of air stability, including the presence of temperature inversions, is the Pasquill-Gifford stability index. This correlates air stability to the thermal gradient of the atmosphere (dT/dz).

Table 2: Stability categories based on dT/dz

Station	Designation
A	$dT/dz < -1.9$
B	$-1.9 \leq dT/dz < -1.7$
C	$-1.7 \leq dT/dz < -1.5$
D	$-1.5 \leq dT/dz < -0.5$
E	$-0.5 \leq dT/dz < -1.5$ (weak inversion)
F	$1.5 \leq dT/dz < 4.0$ (moderate inversion)
G	$4.0 \leq dT/dz$ (strong inversion)

Temperature inversions are most common at night, and are generally considered to have a minimal impact on noise propagation during the daytime. Noise modelling in the EA used the following assumptions when calculating the noise impacts of the proposal on nearby receptors:

Table 3: Predicted stability categories in EA used for noise modelling

Time of day	Pasquill stability class	Wind speed (m/s)
Day (7:00 – 18:00)	C (28%) D (26 %)	4
Evening & Night (18:00 – 7:00)	F (65% - 70%)	2

1.3. Noise Criteria

Condition F10 of the Project Approval conditions defines noise levels that the proposed plant must comply with "under all meteorological conditions except for the following:

(a) Wind speeds greater than 4 metres per second measured at 10 metres above ground level; or

(b) F stability category temperature inversion conditions and wind speeds greater than 2 metres per second at 10 metres above ground level; or

(c) G stability category temperature inversion conditions.

The data to be used for determining meteorological conditions shall be that recorded by the meteorological station located on the project site.

The stability category temperature inversion exceptions detailed in (b) and (c) are not applicable if the report prepared under condition C45 demonstrates that the stability category inversion conditions described in (b) and (c) are characteristic of the area and occur for a significant period of time, unless otherwise agreed to by the Director-General."

Therefore, in addition to the determination of the stability category temperature inversions, the subset of the above criteria was also calculated.

2. Aim

To determine the occurrence of stability category F and G events over the required period using the sigma-theta method.

3. Procedure

3.1. Method

In line with the Project Approval conditions, the following data were recorded at AGL-DT80, at the site of the proposed Dalton Power Project. The site is on a low hill with low to moderate bush cover.

Table 4: Meteorological parameters and units measured as required by Project Approval (s. C41)

Parameter	Units	Averaging Period
Rainfall	mm	1 hour
Wind speed at 10 m	m/s	15 minute
Wind direction at 10 m	m/s	15 minute
Temperature at 2 m	°C	15 minute
Temperature at 10 m	°C	15 minute
Sigma-theta at 10 m	°	15minute
Solar radiation	W/m^2	15 minute
Relative humidity	%	1 hour

The downloaded data were analysed according to Appendix E (Methods for determining the frequency of temperature inversions) of the *NSW Industrial Noise Policy (2000) (INP)*. This document outlines different methods for determining stability categories based on the type of data available. The techniques are:

- Using the temperature gradient as measured over 50 m to determine the presence of inversions
- Using the cloud cover, wind speed and solar elevation to determine the stability as a function of reflected radiation (the main cause of inversions in this instance)
- Using the time-averaged variation in the wind direction (the standard deviation) and wind speed to estimate the stability of the system (the sigma-theta method).

Given that data were not available for the temperature at 50m, and reliable cloud cover data not available at the location, in accordance with the *INP* the sigma-theta method was used.

The sigma-theta method

Outlined in the *INP*, the sigma-theta estimates the Pasquill-Gifford stability category based on the standard deviation of wind direction across the hourly period. The night-time stability may be determined in two steps according to Appendix E of the *INP*:

- Determine the night-time (from 6 pm to 7am) stability from σ_A data using *Table E5* (Table 4 in this document).
- Modify this stability category based on prevailing wind speed using *Table E6* (Table 5 in this document).

Stability categories during the daytime period (8 am to 5 pm given the hourly averaging) are determined using *Table E5* (Table 4) only.

Table 5: Application of wind fluctuation criteria for estimating Pasquill-Gifford stability categories for non-arid areas in NSW

Stability category	Sigma-theta
A	$\sigma_A \geq 22.5°$
B	$17.5° \leq \sigma_A \leq 22.5°$

C	12.5° ≤ σ_A ≤ 17.5°
D	7.5° ≤ σ_A ≤ 12.5°
E	3.8° ≤ σ_A ≤ 7.5°
F	2.1° ≤ σ_A ≤ 3.8°
G	σ_A ≤ 2.1°

This table is only valid for a surface roughness (z_0) of 0.15 m, as was determined to be the case at this site (Appendix A).

Table 6: Application of Night-time Pasquill-Gifford stability categories based on σ_A from table E5 (in the *INP*)

Stability category	Wind speed	Modified stability category
A	• <2.9 • 2.9 – 3.6 • ≥3.6	• F • E • D
B	• <2.4 • 2.4 – 3.0 • ≥3.0	• F • E • D
C	• <2.4 • ≥2.4	• E • D
D	• Any	• D
E, F, G	• ≥5 • 3 – 5 • 2 – 3 • <2	• D • E • F • G

Preliminary determination of the significance and frequency of stability category temperature inversions involves the analysis of the night time winter dataset. However, in line with the Project Approval Conditions (C45), the type and frequency of temperature inversion conditions prevailing at the site required consideration of the entire dataset.

4. Results and discussion

4.1. Winter dataset

As per the *INP*, the significance of temperature inversions is determined by analysing the worst-case scenario, night time during winter (June, July and August). Although for noise impact assessment purposes night is classified as 10pm – 7am, for the determination of temperature inversions the period of 6pm – 7am is used as per the *INP* method. Data were recorded every 5 minutes then averaged to hourly intervals for the calculations in accordance with the *INP*.

Table 7: Winter dataset information

Dataset	Start date	End date	Data recovery
Winter 2013	1:00 1/6/13	24:00 31/8/13	99.91%
Winter 2014	1:00 1/6/14	24:00 31/8/14	97.28%

Table 8: Application of wind fluctuation criteria for estimating Pasquill-Gifford stability categories for non-arid areas in NSW during winter months (Night time – 6 pm to 7 am)

Stability Category	Occurrence	Percentage
A	1644	64.75%
B	457	18.00%
C	306	12.05%
D	126	4.96%
E	6	0.24%
F	0	0.00%
G	0	0.00%
Total	**2539**	**100%**

Table 9: Application of wind fluctuation criteria for estimating Pasquill-Gifford stability categories for non-arid areas in NSW during winter months (Night time – 6 pm to 7 am)

Modified stability category	Occurrence	Percentage
D	142	5.59%
E	332	13.08%
F	2059	81.09%
G	6	0.24%
Total	**2539**	**100%**
Sum total of F and G	2065	81.33%

The total occurrence of night-time moderate and strong inversions over the winter period was 81.33% (Moderate = 81.09% and strong = 0.24%).

Whilst there is a very high occurrence of category F (moderate temperature inversion), there is an extremely low level of G conditions over the winter night period. The high occurrence of category F is largely due to the consistently low wind speed recorded at the site. It is noted that the standard deviation of wind direction is also consistently very high. The combination of low speed and high variation in wind suggests the significant effects from local obstacles obstructing the wind flow, concordant with the site placement in a moderately wooded area. The recorded incidence of moderate and strong temperature inversions is approximately 10-15% higher during the winter than predicted in the EA (which did not specify season).

It should be noted as detailed in Appendix G of the EA that category F was used as the basis for the noise modelling carried out for the Dalton Power Project (rather than category G). This assumption was based on the high predicted levels of stability category F conditions compared to category G (and the similarity of their significance as weighted in the *INP*). The validity of this assumption is supported by the findings of this report, where category G conditions appear to be relatively rare.

4.2. Complete night time dataset

Given that the high occurrence of moderate temperature inversions and the extremely low occurrence of strong temperature inversions have been established, the entire dataset was examined in the same way.

Table 10: Complete dataset information

Dataset	Start date	End date	Data recovery
Night	18:00 3/2/13	22:00 15/10/14	98.17%

The procedure used in s. 4.1 to determine the stability categories of the winter dataset was used again to determine the Pasquill-Gifford stability categories for this dataset.

Table 11: Determined Pasquill-Gifford categories over night-time for complete dataset

Stability Category	Occurrence	Percentage
A	5158	60.73%
B	1864	21.94%
C	1047	12.33%
D	407	4.79%
E	18	0.21%
F	0	0.00%
G	0	0.00%
Total	**3256**	**100%**

The categories were then modified based on their corresponding wind speed, in accordance with Table E6 (Table 3 in this document) in Appendix E of the *INP.*

Table 12: Actual night-time Pasquill-Gifford stability categories for complete dataset

Modified stability category	Occurrence	Percentage
D	612	7.21%
E	1146	13.49%
F	6718	79.09%
G	18	0.21%
Total	**8494**	**100%**

Sum total of F and G	6736	79.30%

The *INP* states that, "the percentage occurrence required here is the total percentage over the time surveyed. The Pasquill-Gifford scheme assumes that moderate and strong inversions do not occur during the daytime hours."

Thus as calculated the total occurrence of night-time moderate and strong inversions over this period was 79.30%. Moderate (stability category F = 79.09% and stability category G = 0.21%)

The determined F and G class categories over this period are higher than those predicted in the EA by 9.30-14.30%. As can be seen in Table 11, the majority of the stability conditions calculated comprised class A and B, generally due to the very high wind direction standard deviation at the site (average σ_A for the night-time dataset was 25.05°). This, in conjunction with the very low average wind speed (average wind speed was 1.06 m/s for the night-time dataset), generated a very high incidence of class F conditions. A relatively low speed and directionally variable (at 10 m altitude) wind pattern is again consistent with the site conditions.

4.3. Daytime dataset

Although not required by the *INP*, the daytime (7 am to 6 pm) dataset was also analysed to confirm the predictions of the EA, and to fulfil Project Approval condition C45. Section 5.2 of Appendix G of the EA predicted class C conditions 28% of the time and class D conditions 26% of the time. Noise modelling was performed on this basis. As per the *INP* method, the results are obtained in a one-step method using *Table E5.* The dataset used included April and May.

Table 13: Daytime dataset information

Dataset	Start date	End date	Data recovery
Daytime	14:00 3/2/13	17:00 15/10/14	98.16%

Table 14: Determined daytime Pasquill-Gifford stability categories

Stability Category	Occurrence	Percentage
A	5131	84.59%
B	687	11.33%
C	211	3.48%
D	34	0.56%
E	3	0.05%
F	0	0.00%
G	0	0.00%
Total	**6066**	**100%**

These calculated stability categories indicate significant divergence from the predicted conditions at the site. Daytime conditions recorded at the site were generally characterised by higher wind direction variation (σ_A was 29.4 averaged across the period). As the daytime sigma-theta method relies entirely on the directional variation, a large percentage of class A conditions was recorded.

4.4. F10 exemption conditions

Condition F10 gives the noise requirements for the Dalton Power Station. The noise propagation is influenced by the meteorological conditions on site.

Condition F10 also outlines conditions under which the noise restrictions are not applicable, specifically:

(a) Wind speeds greater than 4 m/s at the measured height (10 m above ground level)
(b) Category F stability conditions coinciding with wind speeds greater than 2 m/s
(c) Category G stability conditions

Exemptions (b) and (c) only apply if it is determined that (b) and (c) are not characteristic of the area and do not apply for a significant period of time.

Filtering was applied to the complete dataset and subsets to determine the occurrence of the conditions listed in section F10 of the Conditions.

Table 15: Occurrence of F10 conditions[1]

Dataset	A	B	C	Sum of B and C	Total
Complete	108 (0.74%)	512 (3.52%)	18 (0.12%)	530 (6.24%)	**638 (4.38%)**
Winter nights	4 (0.16%)	156 (6.14%)	6 (0.24%)	162 (6.38%)	**166 (6.54%)**
All nights	33 (0.39%)	512 (6.03%)	18 (0.21%)	530 (6.24%)	**563 (6.63%)**
Days	75 (1.24%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	**75 (1.24%)**
Morning peak period (5am – 8am)	1 (0.04%)	87 (3.59%)	1 (0.04%)	88 (3.63%)	**89 (3.67%)**
Evening peak period (4pm – 9pm)	50 (1.37%)	207 (5.67%)	7 (0.19%)	214 (5.87%)	**264 (7.24%)**

Note 1: Percentage values are of that respective dataset

Potential peak periods were identified and the F10 condition occurrence of these determined as a subset of the dataset. The morning and evening periods were selected based on the likelihood of temperature inversions and high power demand respectively. These subsets are indicative only.

The significance criterion was taken to be as described in the *INP* (30% of the time). As exemptions (b) and (c) were not found to approach an occurrence of 30% within any dataset (including AGL's peak times), they are not significant of the area and therefore the exemptions will still apply under these conditions.

Table 16: F10 morning dataset information

Dataset	Start date	End date	Data recovery
Morning	05:00 4/2/13	08:00 15/10/14	98.22%

Table 17: F10 evening dataset information

Dataset	Start date	End date	Data recovery
Evening	16:00 3/2/13	21:00 15/10/14	98.38%

5. Conclusion

Recorded data indicate that, as predicted in the EA, moderate stability temperature inversions (class F) are prevalent for the majority of the night-time hourly periods at the site of the Dalton Power Project. The occurrence of class F conditions was slightly higher than predicted, with F and G conditions recorded at the site for 79.30% of night-time periods from February 2013 to October 2014 compared to 65% assumed in the EA.

6. References

1. Full meteorological and air quality reports, with up to 5 minute averaging periods can be obtained from the station website, http://agl.webhop.net/AGL/.
2. *AGL Dalton Power Project Environmental Assessment,* 2011, AGL Energy Ltd
3. *A Practical Method for Determining Wind Frequency Distributions for the Lowest 200 m from Routine Meteorology Data,* 1978, Smedman-Hogstrom, A-S, Hogstrom, U., University of Uppsala. The appendix provides a table of values of z_o for different terrain types.

Appendix A – Determination of the aerodynamic surface roughness z_o

The surface roughness, z_o, is a coefficient applied to Table E5 ('Wind fluctuation criteria for estimating Pasquill-Gifford stability categories for non-arid areas in NSW') of Appendix E of the *NSW Industrial Noise Policy (2000).* The surface roughness essentially profiles low altitude wind flow over different types of terrain, by providing a correlation between a series of boundary layers up to the uninterrupted flow. This correlation is determined using averages given different obstacles, such as trees, hedges and buildings, and uses somewhat subjective parameters such as "fairly level wooded country".[3] z_0 is the average surface roughness within a radius of 1 to 3 km.

z_o is used to modify Table E5 via a weak power law:

$$\sigma_A^* = \sigma_A \left(\frac{z_o}{0.15}\right)^{0.2}$$

(Eq. 1)

Where:
z_o =the surface roughness coefficient (m)
σ_A* = the modified value of Table E5
σ_A = the initial value of Table E5

Given the terrain in the vicinity of the Dalton Power Project is predominantly sparse bush and scrub, the z_o value of 0.15 m was retained. This value fits the referenced table, as the lower value of "many trees, hedges, few buildings".

Appendix B – Other meteorological data measured

As part of the monitoring, and in line with the requirements of the Project Approval, other parameters were measured over the period:

Table 18: Meteorological parameters and units measured as required by Project Approval (s. C41)

Parameter	Units	Averaging Period
Rainfall	mm	1 hour
Wind speed at 10 m	m/s	15 minute
Wind direction at 10 m	m/s	15 minute
Temperature at 2 m	°C	15 minute
Temperature at 10 m	°C	15 minute
Sigma-theta at 10 m	°	15minute
Solar radiation	W/m²	15 minute
Relative humidity	%	1 hour

Note: Data were not recorded from 1650 on 16 April 2013 to 1710 on 16 April 2013. Due to the nature of the graphing software this discontinuity is misleadingly represented as a steady gradient on the line graphs.

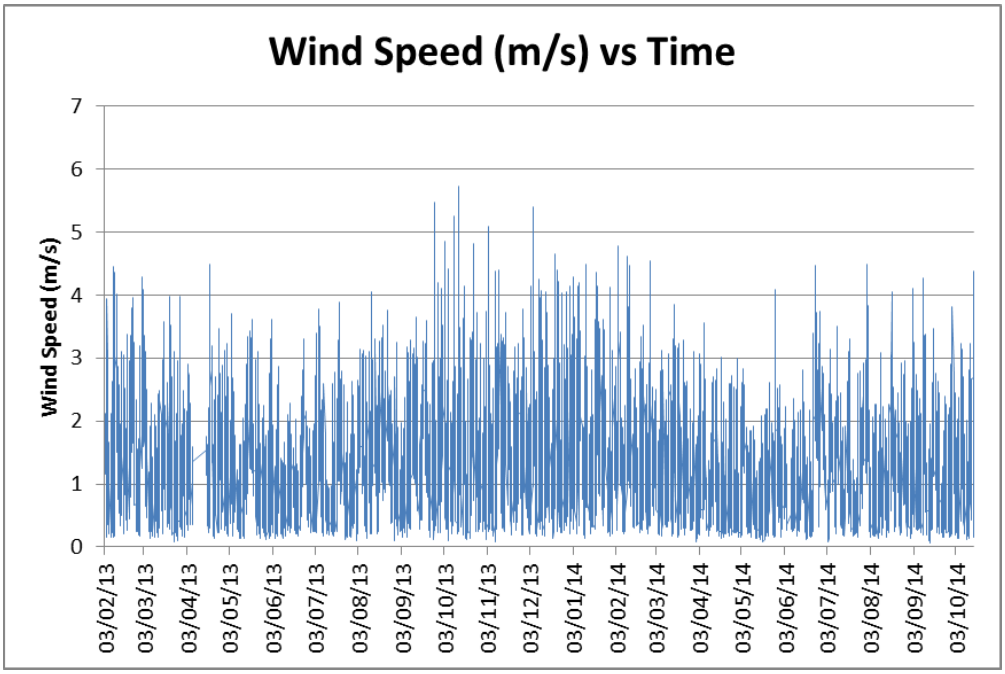


Figure 2: Wind speed for 3 February 2013 – 15 October 2014

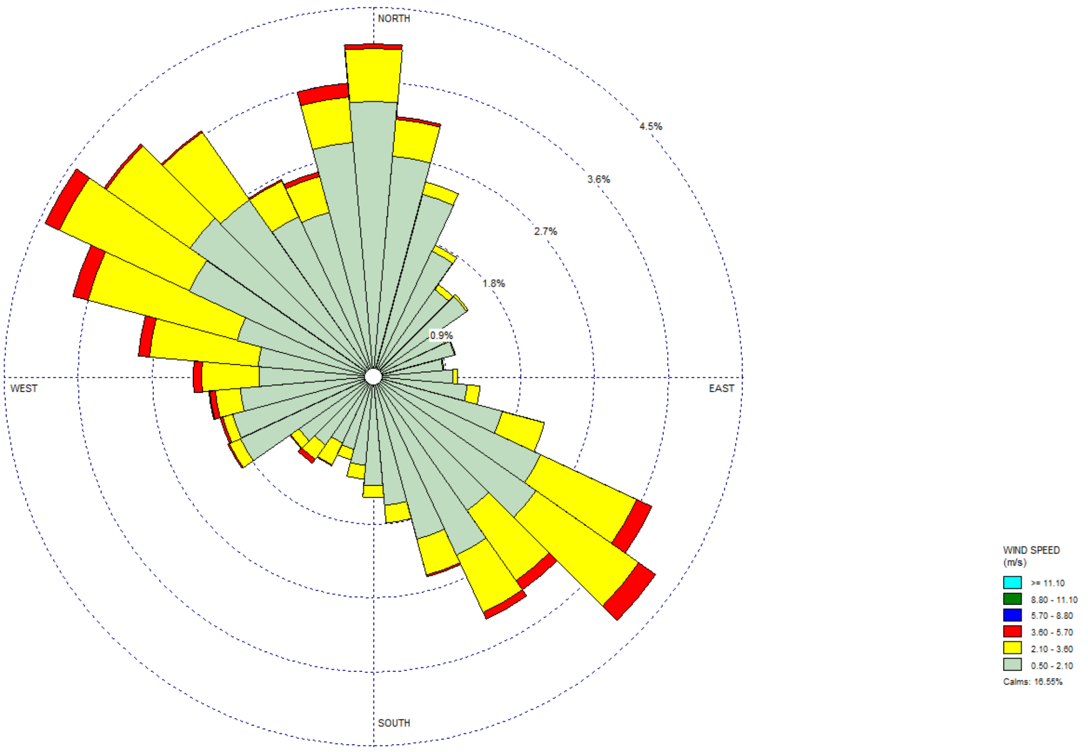


Figure 3: Wind rose for 3 February 2013 – 15 October 2014.

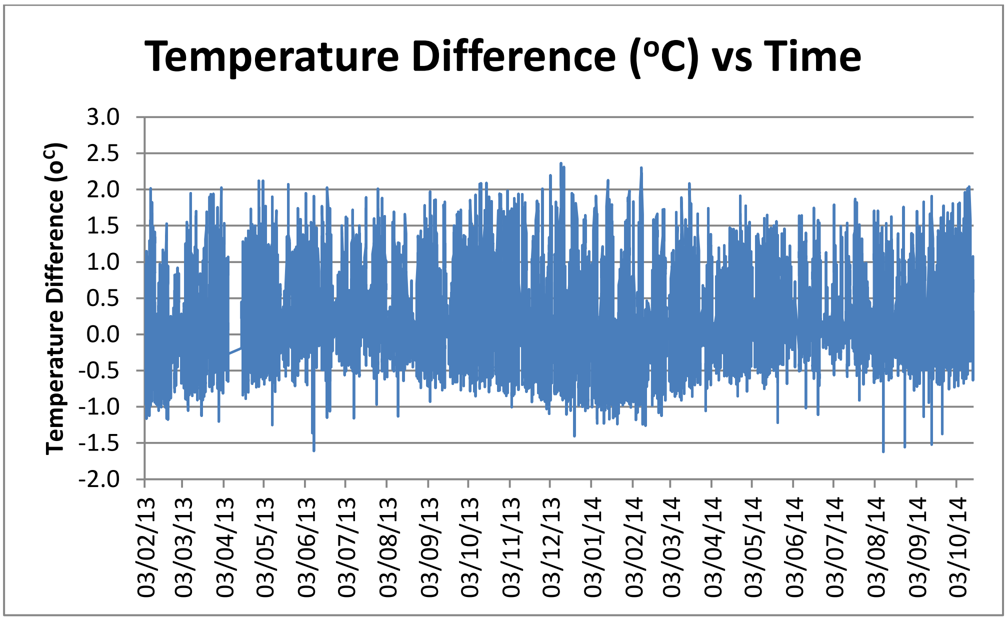


Figure 4: Measured temperature difference for 3 February 2013 – 15 October 2014 (temperature at 10 metres subtracting temperature at 2 metres – a positive value indicates an inversion over this range).

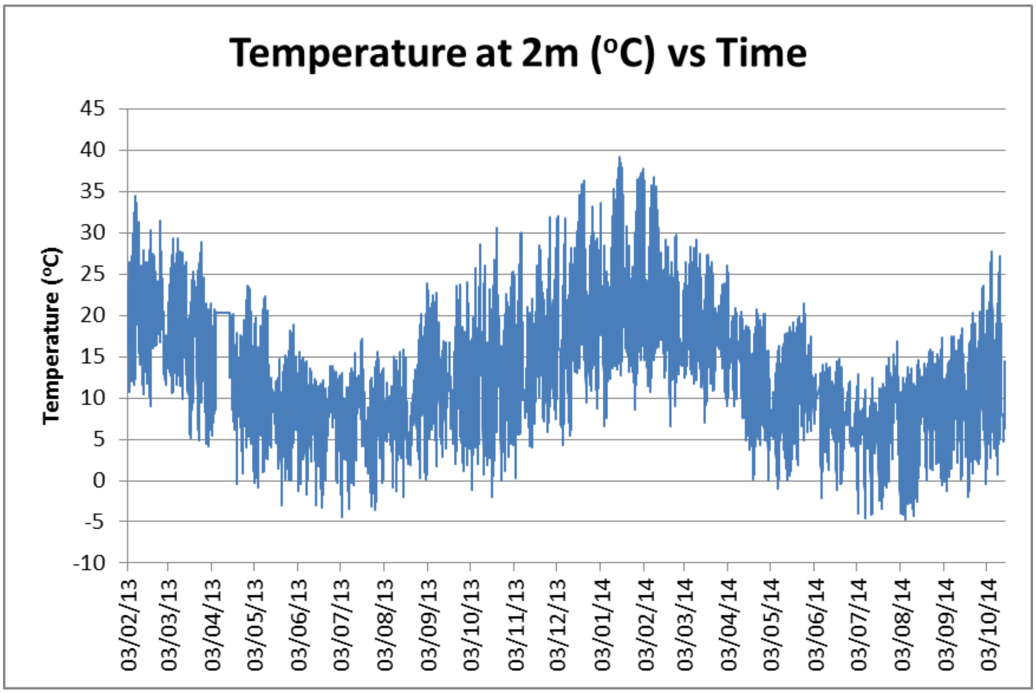


Figure 5: Temperature at 2 m for 3 February 2013 – 15 October 2014

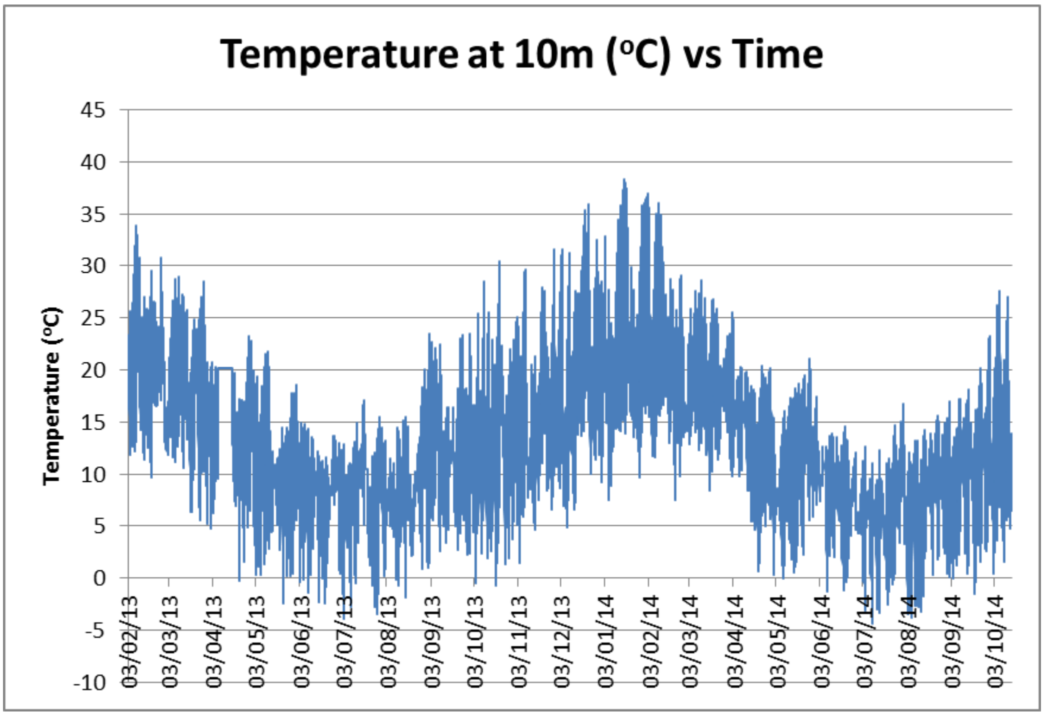


Figure 6: Temperature at 10 m for 3 February 2013 – 15 October 2014

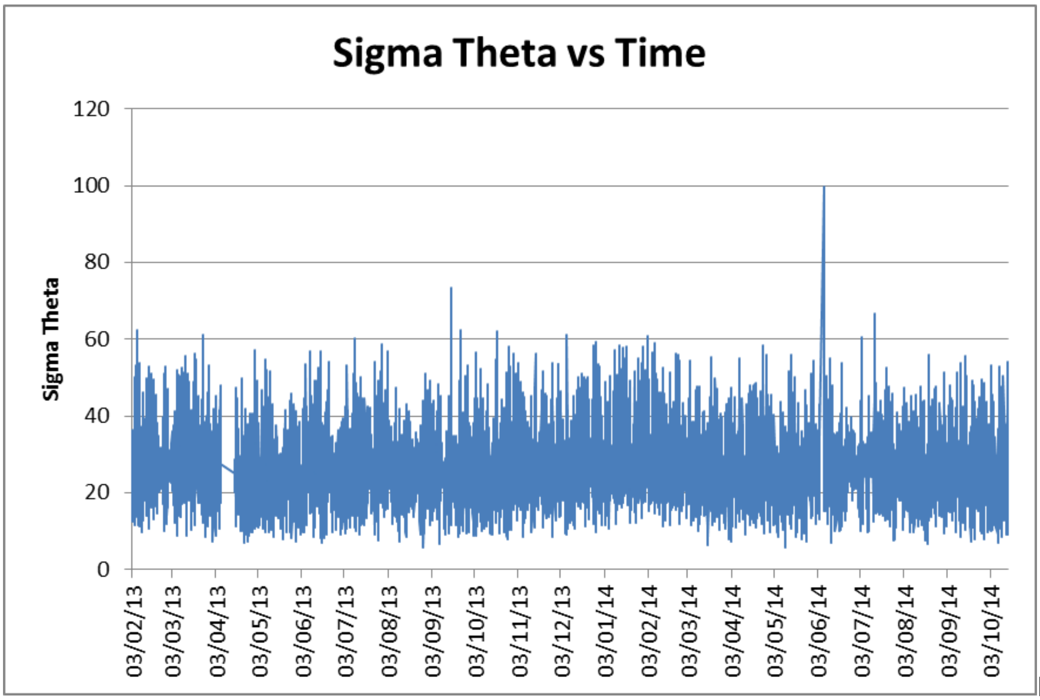


Figure 7: Sigma-theta for 3 February 2013 – 15 October 2014

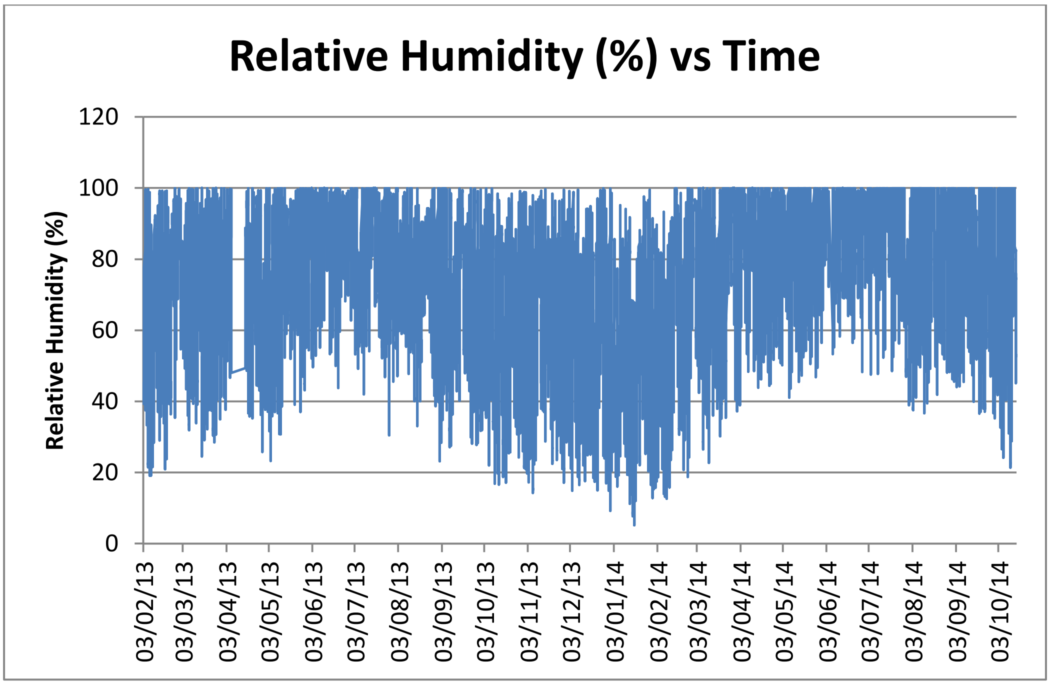


Figure 8: Relative humidity for 3 February 2013 – 15 October 2014

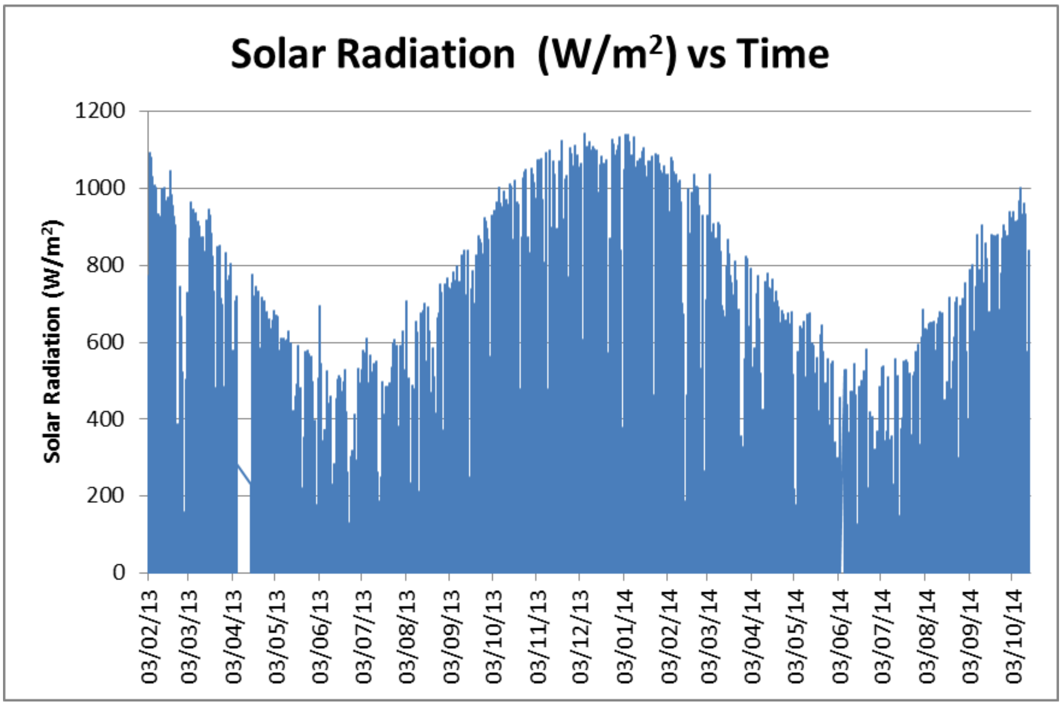


Figure 9: Solar radiation for 3 February 2013 – 15 October 2014

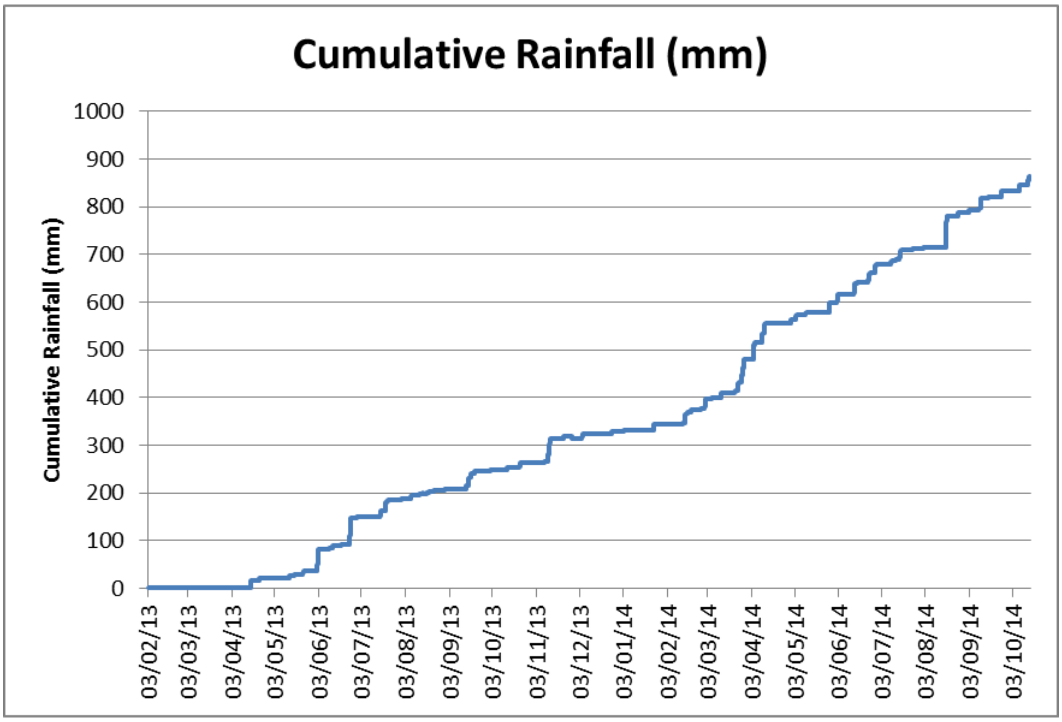
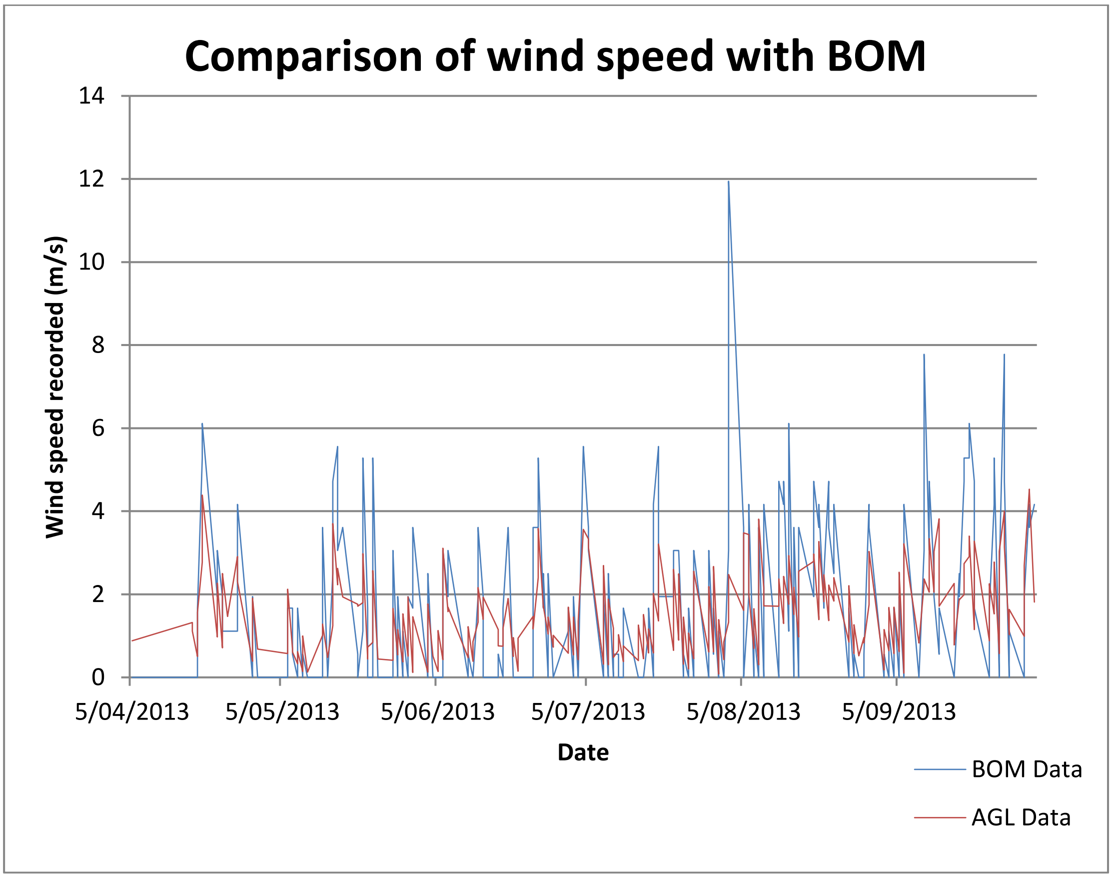


Figure 10: Cumulative Rainfall for 3 February 2013 – 15 October 2014

Appendix C – Comparison with BOM data

In order to confirm the accuracy of the analysis performed, the data obtained were, where possible, compared with data obtained from the Bureau of Meteorology station at Yass (148.91E, 34.82S). Although the BOM station is 46.58 km away, limited in the sensitivity of recording (the minimum recorded wind speed is 2 km/h) and only records on weekdays, the data were compared as an estimation of the accuracy of AGL-DT80.

Figure 11: Recorded wind speed at AGL-DT80 vs. recorded wind speed at Bureau of Meteorology station at Yass



Appendix D – Document listing

Datasets used for calculations and graphs

"20131014 – Met results complete to accompany report_Updated.xlsx"

- Tab 1 "Summary contains summary blocks for each dataset, including the F10 conditions
- Tab 2 "Complete dataset" contains the data used throughout the report
- Tab 3 "All nights" contains the night data (6pm to 7 am)
- Tab 4 "All Days" contains the daytime data (8am to 5 pm)
    - Note there is no gap as the data averaging was centred around the hour mark (for example 4:00 is the average of 3:35 to 4:30)
- Tab 5 "All Winter Nights" contains the night time data for June to August 2013 and 2014
- Tab 6 "5am-8am Dataset F10 Conditions" contains the morning peak data and F10 calculations
- Tab 7 "4pm-9pm Dataset F10 Conditions" contains the evening peak data and F10 calculations
- Tab 8 "Graph Data and Graphs" contains the data used in the graphs in this document.

Raw datasets

"20131029 - Met_data_raw.xls"

- This file contains the raw data as downloaded by AGL from the station website on 29/10/2013.

"AGLmeteo-3Feb-4April2013.xlsx"

- This file contains the raw data from 3/2/2013 to 3/4/2013 as provided to AGL by Lear Siegler.

"20140728 - Weather station data from 3rd October 2013 to 5th June 2014.xlsx"

"20140828 - Meteo Station Data from 4 Jun 2014 to 26 Aug 2014.xlsx"

"20141016 - Weather station data from 25th August 2014 to 15th October 2014.xlsx"

- These files contain the raw data from 3/10/2013 to 15/10/2014.