

Appendix D

Western Sydney Airport Usability Report

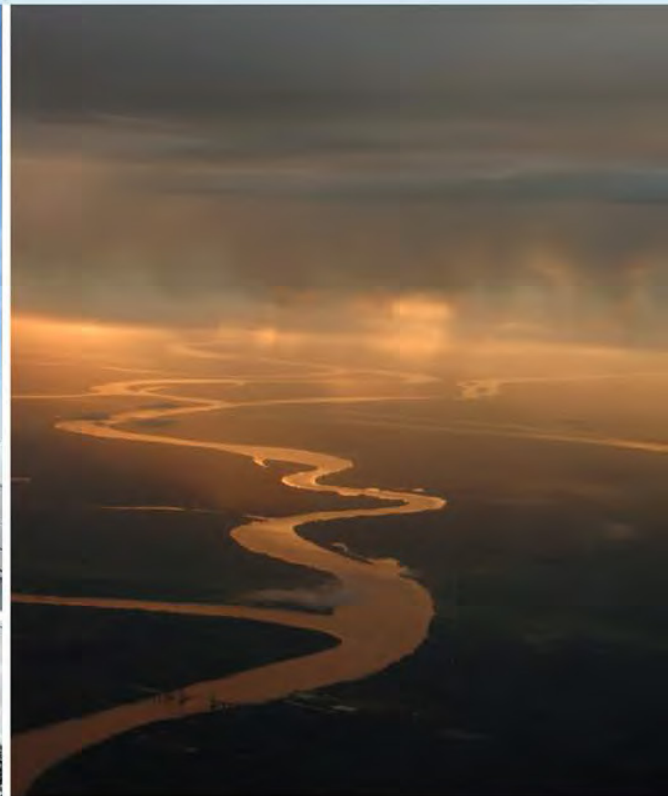




Australian Government
Bureau of Meteorology

Western Sydney Airport Usability Report

Meteorological Impacts



Address comments to:

Head of Aviation and Defence Weather Services

Bureau of Meteorology

GPO Box 1289

Melbourne VIC 3001

Email: stad@bom.gov.au

Ph: 03 9669 4545

Version number/type

Date of issue

1

8/04/2015

© Commonwealth of Australia 2015

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968*, no part may be reproduced without prior written permission from the Bureau of Meteorology. Requests and inquiries concerning reproduction and rights should be addressed to the Communication Section, Bureau of Meteorology, GPO Box 1289, Melbourne 3001. Requests for reproduction of material from the Bureau website should be addressed to AMDISS, Bureau of Meteorology, at the same address.

Table of contents

Executive summary	viii
1 Introduction	1
1.1 Bureau of Meteorology Aviation Weather Services	1
1.2 Badgerys Creek automatic weather station	1
1.3 Department of Infrastructure and Regional Development	2
1.4 Liability	3
2 Wind	4
2.1 Topographic wind effects	4
2.1.1 Anabatic wind	4
2.1.2 Katabatic wind	4
2.1.3 Valley flows	4
2.2 Wind speed and direction	5
2.2.1 Summer and autumn	6
2.2.2 Winter and spring	6
2.3 Percentage wind frequency table	6
2.4 Wind gusts	8
2.4.1 Summer and autumn	9
2.4.2 Winter and spring	9
2.5 Runway nomination	9
2.5.1 Crosswind	9
2.5.2 Headwind	13
2.6 Discussion	15
3 Temperature	16
3.1 Mesoscale effects	16
3.1.1 Coastal effects	16
3.1.2 Foehn effect	16
3.2 Temperature climatology	16
3.3 Temperature extremes	17
3.4 High temperatures	17
3.4.1 Temperatures exceeding 30°C	18
3.4.2 Temperatures exceeding 35°C	19
3.4.3 Temperatures exceeding 40°C	20
3.5 Low temperatures	21
3.5.1 Temperatures below 0°C	21
3.5.2 Frost	22
3.6 Freezing fog	24
3.7 Temperature inversions	25
3.8 Discussion	26
4 Rainfall	27
4.1 Rainfall climatology	27
4.1.1 Mean monthly rainfall comparison	28
4.1.2 Highest monthly rainfall comparison	29
4.1.3 Lowest monthly rainfall comparison	29
4.1.4 Highest daily rainfall comparison	30
4.2 Monthly rain day climatology	30
4.2.1 Mean monthly rain day comparison	31
4.2.2 Highest monthly rain day comparison	32
4.2.3 Lowest monthly rain day comparison	32
4.3 Discussion	33
5 Fog and low cloud	34

5.1	Fog types	34
5.1.1	Radiation fog	34
5.1.2	Advection fog	35
5.1.3	Valley fog	35
5.1.4	Sea fog	35
5.1.5	Advected fog	35
5.1.6	Freezing fog	36
5.2	Fog climatology	36
5.2.1	Fog days with visibility below 1000m	36
5.2.2	Fog days with visibility below 500m	38
5.2.3	Hourly visibility statistics below 1500m	40
5.2.4	Hourly visibility statistics below 800m	44
5.3	Low cloud	46
5.3.1	Low cloud at Badgerys Creek	47
5.3.2	Low cloud at Camden Airport	48
5.4	Discussion	50
6	Turbulence	51
6.1	Turbulence types	51
6.1.1	Mechanical turbulence	51
6.1.2	Rotors	51
6.1.3	Thermals	52
6.1.4	Convective turbulence	52
6.1.5	Frontal turbulence	52
6.1.6	Wake turbulence	53
6.1.7	Low-level vertical wind shear	53
6.2	Numerical modelling of turbulence	53
6.3	Severe turbulence	54
6.4	Moderate turbulence	55
6.5	Low-level vertical wind shear	56
6.6	Discussion	57
7	Thunderstorms	58
7.1	Thunderstorm properties	58
7.2	Lightning data	58
7.3	Lightning within 5nm	59
7.3.1	Monthly climatology	59
7.3.2	Hourly climatology	60
7.3.3	Lightning days within 5nm	60
7.4	Lightning within 10nm	61
7.4.1	Monthly climatology	61
7.4.2	Hourly climatology	62
7.4.3	Lightning days within 10nm	63
7.5	Lightning within 45nm	64
7.5.1	Monthly climatology	64
7.5.2	Hourly climatology	64
7.5.3	Lightning days within 45nm	65
7.6	Discussion	66
8	Conclusion	67
9	References	68

List of acronyms and abbreviations

Airservices	Airservices Australia
AWS	Automatic Weather Station
Bureau	Bureau of Meteorology
CASA	Civil Aviation Safety Authority
CCN	Cloud Condensation Nuclei
DIRD	Department of Infrastructure and Regional Development
LIDAR	Laser Imaging, Detection And Radar
Sydney KSA	Sydney Kingsford Smith Airport
Richmond	RAAF Base Richmond
RVR	Runway Visual Range
WSA	Western Sydney Airport

List of tables

Table 2-1 Table of percentage occurrence for selected wind direction and speed categories	7
Table 2-2 Table of historical percentage direction of crosswind >20kts	10
Table 2-3 Table of historical percentage direction of crosswind >25kts	11
Table 2-4 Table of percentage direction of crosswind >30kts	12
Table 2-5 Table of percentage direction of headwind >25kts	13
Table 2-6 Table of percentage direction of headwind >30kts	14
Table 3-1 Temperature climatology for Badgerys Creek	17
Table 3-2 Temperature climatology extremes for Badgerys Creek	17
Table 4-1 Rainfall climatology for Badgerys Creek	27
Table 4-2 Rain day climatology for Badgerys Creek	30
Table 5-1 Summary table of calculated statistics for visibility <1000m	38
Table 5-2 Summary table of calculated statistics for visibility <500m	39
Table 5-3 Table of monthly percentage occurrence of visibility <1500m for each hour of the day at Camden Airport	41
Table 5-4 Comparison table of percentage occurrence of visibility <1500m for each hour of the day in June and July	42
Table 5-5 Table of percentage monthly occurrence of visibility <800m for each hour of the day at Camden Airport	44
Table 5-6 Comparison table of percentage likelihood of visibility <800m for each hour of the day in June and July	45
Table 5-7 Aircraft category and corresponding alternate cloud minima	47

List of figures

Figure 1 Depiction of preliminary report findings for WSA in comparison with Sydney KSA	viii
Figure 1.1 Site photograph of Badgerys Creek AWS	1
Figure 1.2 Topographical map of Sydney Basin	2
Figure 1.3 1997-99 EIS Master plan option A for WSA The white balloon shows the current location of the Badgerys Creek AWS	3
Figure 2.1 Seasonal wind rose for Badgerys Creek	5
Figure 2.2 Seasonal wind gust rose for Badgerys Creek	8
Figure 2.3 Average number of days per month of crosswind >20kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34	10
Figure 2.4 Average number of days per month of crosswind >25kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34	11
Figure 2.5 Average number of days per month of crosswind >30kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34	12
Figure 2.6 Average number of days per month of headwind >25kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34	13

Figure 2.7 Average no. of days per month of headwind >30kts on WSA runway 05/23 and Sydney KSA runway 16/34	14
Figure 3.1 Average hours of temperature $\geq 30^{\circ}\text{C}$ at Badgerys Creek.....	18
Figure 3.2 Boxplot of average hourly occurrence of temperature exceeding 30°C at Badgerys Creek.....	18
Figure 3.3 Average hours of temperature $\geq 35^{\circ}\text{C}$ at Badgerys Creek.....	19
Figure 3.4 Boxplot of average hourly occurrence of temperature $\geq 35^{\circ}$ at Badgerys Creek.....	19
Figure 3.5 Average hours of temperature $\geq 40^{\circ}\text{C}$ at Badgerys Creek.....	20
Figure 3.6 Boxplot of average hourly occurrence of temperature $\geq 40^{\circ}$ at Badgerys Creek.....	20
Figure 3.7 Average hours of temperature $\leq 0^{\circ}$ at Badgerys Creek	21
Figure 3.8 Hourly occurrence of temperatures $\leq 0^{\circ}$ at Badgerys Creek.....	21
Figure 3.9 Average hourly inferred frost occurrence at Badgerys Creek	22
Figure 3.10 Average hourly inferred frost occurrence at Canberra Airport.....	22
Figure 3.11 Hourly inferred frost occurrence at Badgerys Creek.....	23
Figure 3.12 Hourly inferred frost occurrence at Canberra Airport	23
Figure 3.13 Average hours of inferred freezing fog occurrence at Badgerys Creek.....	24
Figure 3.14 Average hours of inferred freezing fog occurrence at Canberra Airport.....	24
Figure 3.15 Hourly inferred freezing fog occurrence at Badgerys Creek	25
Figure 3.16 Hourly inferred freezing fog occurrence at Canberra Airport.....	25
Figure 4.1 Monthly rainfall climatology at Badgerys Creek.....	28
Figure 4.2 Comparison graph of mean monthly rainfall	28
Figure 4.3 Comparison graph of highest monthly rainfall	29
Figure 4.4 Comparison graph of lowest monthly rainfall.....	29
Figure 4.5 Comparison graph of highest daily rainfall.....	30
Figure 4.6 Mean monthly rain days at Badgerys Creek.....	31
Figure 4.7 Comparison graph of mean monthly rain days	31
Figure 4.8 Comparison graph of highest monthly rain days.....	32
Figure 4.9 Comparison graph of lowest monthly rain days	32
Figure 5.1 Illustration of Radiation Fog and Post Rain Fog Formation Processes (Bureau 2014).....	34
Figure 5.2 Illustration of Advection Fog Formation Processes (Bureau 2014)	35
Figure 5.3 Illustration of Advection Fog Formation Processes (Bureau 2014)	35
Figure 5.4 Monthly bar graph of number of days with visibility <1000m at Camden Airport.....	37
Figure 5.5 Monthly bar graph of number of days with fog events at Camden Airport.....	37
Figure 5.6 Monthly bar graph of number of days with visibility <500m at Camden Airport.....	38
Figure 5.7 Monthly bar graph of number of days with fog events at Camden Airport.....	39
Figure 5.8 Line graph of percentage occurrence of visibility <1500m for each hour of the day in June	43
Figure 5.9 Line graph of percentage occurrence of visibility <1500m for each hour of the day in July.....	43

Figure 5.10 Line graph of percentage occurrence of visibility <800m for each hour of the day in June	46
Figure 5.11 Line graph of percentage occurrence of visibility <800m for each hour of the day in July	46
Figure 5.12 Histogram of monthly average dewpoint depression at Badgerys Creek	47
Figure 5.13 Histogram of hourly average dewpoint depression at Badgerys Creek.....	48
Figure 5.14 Percentage hourly occurrence of cloud base <1500ft.....	49
Figure 5.15 Percentage hourly occurrence of cloud base <1000ft.....	49
Figure 5.16 Percentage hourly occurrence of cloud base <500ft.....	50
Figure 6.1 Example of effects of obstacle on fluid flow (Bureau, 2014)	51
Figure 6.2 Turbulence in lee mountain environment (Bureau, 2014)	52
Figure 6.3 Vertical wind shear configurations (Bureau 2014)	53
Figure 6.4 Monthly occurrence of severe turbulence.....	54
Figure 6.5 Hourly occurrence of severe turbulence	55
Figure 6.6 Monthly occurrence of moderate turbulence	55
Figure 6.7 Hourly occurrence of moderate turbulence.....	56
Figure 6.8 Comparison graph of monthly occurrence rates of severe wind shear	56
Figure 6.9 Comparison graph of hourly occurrence rates of severe wind shear	57
Figure 7.1 Monthly graph of lightning strikes within 5NM of Sydney KSA, WSA and Brisbane Airport.....	59
Figure 7.2 Hourly graph of lightning strikes within 5nm of Sydney KSA, WSA and Brisbane Airport.....	60
Figure 7.3 Monthly graph of lightning days within 5NM of WSA since Feb 2008	60
Figure 7.4 Monthly graph of lightning days within 5NM of Sydney KSA since Feb 2008	61
Figure 7.5 Monthly graph of lightning strikes within 10NM of Sydney KSA, WSA and Brisbane Airport.....	62
Figure 7.6 Hourly graph of lightning strikes within 10NM of Sydney KSA, WSA and Brisbane Airport.....	62
Figure 7.7 Monthly graph of lightning days within 10NM of WSA since Feb 2008	63
Figure 7.8 Monthly graph of lightning days within 10NM of Sydney KSA since Feb 2008	63
Figure 7.9 Monthly graph of lightning strikes within 45NM of Sydney KSA, WSA and Brisbane Airport.....	64
Figure 7.10 Hourly graph of lightning strikes within 45NM of Sydney KSA, WSA and Brisbane Airport.....	65
Figure 7.11 Monthly graph of lightning days within 45NM of WSA since Feb 2008	65
Figure 7.12 Monthly graph of lightning days within 45NM of Sydney KSA since Feb 2008	66

Executive summary

In 2014 the Bureau of Meteorology was engaged by the Australian Government Department of Infrastructure and Regional Development (DIRD) to provide a preliminary report on the meteorological parameters affecting the usability of the Badgerys Creek site for the development of the Western Sydney Airport (WSA).

With respect to the planned nomination of runways at Badgerys creek, it is expected that the current runway configuration proposed will be usable approximately 99.5% of the time based on crosswinds alone. Other weather phenomena such as fog, low cloud and low visibility conditions may lower the usability of the airport; however mitigation is obtainable through navigational systems and aids.

The major outcomes of the preliminary report have been summarised in Figure 1.

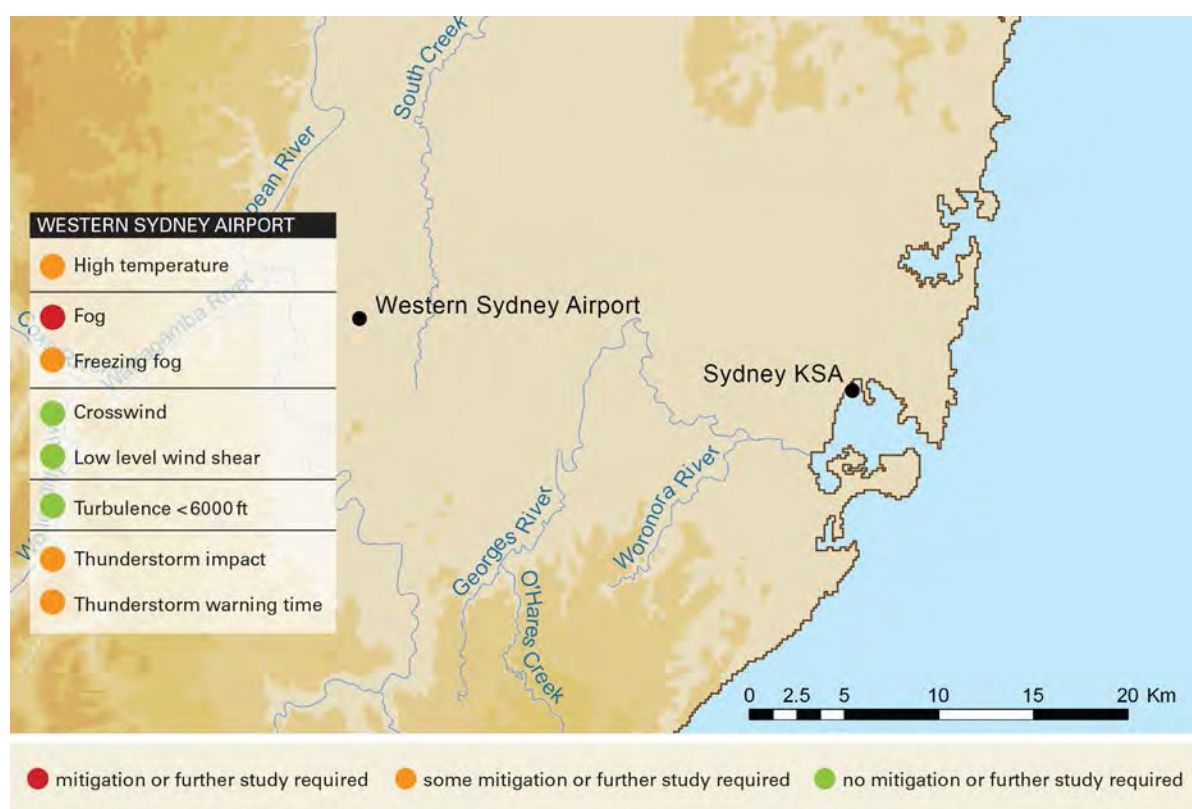


Figure 1 Depiction of preliminary report findings for WSA in comparison with Sydney KSA

Wind

- WSA experiences crosswind effects in the 05/23 direction on average half as often as Sydney KSA does in the 16/34 direction. The months of August to October are the most probable times to experience a crosswind exceeding 20kts at WSA in the 05/23 direction.
- Headwinds in excess of 25kts would be rare at WSA. Sydney KSA is approximately 4 times more likely to experience headwinds on the 16/34 parallel runways than WSA is on the proposed 05/23 runway.
- Headwinds in excess of 25kts are not expected to occur on average more than 0.4 days per month for any month of the year at WSA; whereas headwinds in excess of 25kts occur at Sydney KSA more than 0.8 days per month from September to March.

Temperature

- High temperatures ($\geq 35^{\circ}\text{C}$) at WSA can occur from October to March but would be more prevalent in the months of November to February with more than 7 hours per month expected on average. High temperatures ($\geq 35^{\circ}\text{C}$) at WSA would be most likely in the period from middle to late afternoon. Although temperatures above 35°C do not occur frequently, they have the ability to restrict jet fuel loading.
- Low temperatures ($\leq 0^{\circ}\text{C}$) occur frequently in the months June to August at Badgerys Creek where on average. Temperatures are most likely to drop below 0°C in July, where there is in average of more than 75 hours a month. On the days that the temperature is recorded below 0°C , it is the early morning before sunrise when this is most likely to occur.
- Low temperature including conditions conducive to the formation of freezing fog occurs at Badgerys Creek from May to September with an average maximum of 3.5 hours in July. Canberra Airport experiences on average 10 times more hours a month in winter where freezing fog has the potential to form than would be expected at WSA
- The presence of a temperature inversion has a significant influence on the ability of the atmosphere to disperse pollutants. Further study into inversion levels would be necessary for the calculation of pollution parameters.

Rainfall

- Badgerys Creek receives slightly less rainfall per month than Camden Airport, and significantly less than Sydney KSA outside of thunderstorm season (October – March).

Turbulence

- Little to no low level severe wind shear is expected at WSA in comparison to Sydney KSA which experiences on average one hour per day in the months of August to December.
- Numerical modelling of atmospheric winds at Badgerys Creek shows that turbulence at WSA is predominantly expected to be caused by mechanical turbulence due to the Great Dividing Range.
- Moderate turbulence at WSA would be most likely in the months from June to August with on average five hours per day expected. Moderate turbulence at WSA would be most likely during the evening and overnight periods. In comparison, Sydney KSA could experience moderate turbulence at any time of the day but is most likely in the months from June to August.

- Over the 5yrs (2010-2014) of model data analysed WSA would have been expected to experience 1140 hours of moderate turbulence per year, whereas Sydney KSA would have been expected to have on average 1520 hours.
- Severe turbulence at WSA would be most likely in the months from June to August with on average three hours per day expected. Severe turbulence at WSA would be most likely during the evening and overnight periods. Moreover, Sydney KSA could experience severe turbulence at any time of the day but is most likely in the months from June to August.
- Over the 5yrs (2010-2014) of model data analysed WSA would have been expected to experience 545hrs of severe turbulence per year; whereas Sydney KSA would have been expected to have on average 735 hours.
- With the current wind analysis it is not possible to determine whether rotors would affect WSA.

Thunderstorms

- Thunderstorms and associated lightning is generally expected to form earlier in the day at WSA than Sydney KSA. Also, the thunderstorm season appears to both start and finish earlier at WSA than Sydney KSA.
- Overall, WSA would have experienced 632 less lightning strikes within 5nm, 1095 less lightning strikes within 10nm, and 2161 less lightning strikes within 45nm than Sydney KSA since February 2008.

The following outcomes have been found for Camden Airport. Camden Airport has been chosen as a representative site for WSA with regards to fog and low cloud data analysis:

Fog

- Fog at Camden Airport occurring for a period of an hour or more averaged 23% of days per year. The percentage increased to 40% of days per month during winter. Fog occurring for periods of four hours or more averaged 5% of days per year, increasing to 12% of days per month during winter.
- Fog occurs approximately 30 times more often at Camden Airport than at Sydney KSA during June and July; and approximately twice more likely at Camden Airport than at Canberra Airport, during June and July.

Low Cloud

- A cloud ceiling with broken or overcast cloud below 1500ft is approximately twice more likely at Camden Airport than Canberra Airport for all months except those in winter where both Camden and Canberra Airport experience a similar frequency of cloud with ceilings below 1500ft.
- A cloud ceiling with broken or overcast cloud below 1000ft is approximately 5 times more common at Camden Airport than Canberra Airport for all months except those in winter where Camden Airport only slightly exceeds Canberra Airport for the frequency of cloud with ceilings below 1000ft.
- A cloud ceiling with broken or overcast cloud below 500ft is approximately 3 times more likely at Camden Airport than at Canberra Airport for all months of the year.

Recommendations:

1. Clearance of vegetation to the west and south-west direction of the airport should be avoided as reducing drag may cause increases in wind speeds from downslope winds. (Page 15)
2. Orientation of buildings containing large surface areas should avoid the direction of strongest wind (westerly sector) as much as possible to avoid creating turbulent effects. (Page 15)
3. The effect of high temperatures may need to be considered during the construction of jet fuel facilities at WSA. (Page 26)
4. De-icing equipment may need to be considered in order to optimise operations at WSA during periods of low temperature. (Page 26)
5. Changes in land surface coverage will need to be accounted for in hydrological studies to ensure appropriate control measures and engineering can mitigate surface runoff. (Page 33)
6. Automatic instrumentation for cloud and visibility should be installed for the collection of climatological information and for the production of forecast products in future. (Page 50)
7. Appropriate low visibility landing equipment, such as runway visual range (RVR) needs to be considered in order to optimise operations at WSA. (Page 50)
8. A Doppler LIDAR system at Badgerys Creek can provide the necessary information for observing wind movement in the lower atmosphere including detection of wind shear and rotors. The Doppler LIDAR system is costly and a cost-benefit analysis would be recommended. (Page 57)
9. The Bureau implements an Automated Thunderstorm Alert Service (ATSAS) at WSA to improve the accuracy of thunderstorm forecasting for the airport whilst increasing the operational safety of ground staff and aircraft.

1 Introduction

1.1 Bureau of Meteorology Aviation Weather Services

The Bureau of Meteorology's (Bureau's) role in providing services for civil aviation is established through the Meteorology Act. Under the Convention for International Civil Aviation (the Chicago Convention) the Bureau is the designated Meteorological Authority for Australia and also provides meteorological services for civil aviation in Australia in accordance with the standards and practices set out in Annex 3 to the Convention.

In fulfilling this mandate it works closely with Airservices Australia (Airservices), which is responsible for air traffic services, and the Civil Aviation Safety Authority (CASA), which is responsible for the safety regulation of civil aviation in Australia.

1.2 Badgerys Creek automatic weather station

In 1995 the Bureau installed an Automatic Weather Station (AWS) at Badgerys Creek, (Lat 33.9S, Long 150.7E) which sits at an elevation of 81.2m (Figure 1.1). Since this time, a continuous supply of meteorological information including wind, temperature, dewpoint temperature, pressure and rainfall has been collected in order to build climatology of the local area. Owing to the location of the future Western Sydney Airport (WSA) site in the western Sydney Basin, the climate and weather phenomena that affect Badgerys Creek can be significantly different to those experienced at Sydney Kingsford Smith Airport (Sydney KSA).



Figure 1.1 Site photograph of Badgerys Creek AWS

Topographical differences across the Sydney Basin are the primary cause of weather variations in eastern New South Wales (NSW). Topography is likely to cause local disparities in temperature, moisture, pressure, rainfall and wind. Any combination of these factors will indirectly affect the frequency and severity of weather phenomena such as fog, thunderstorms, turbulence, wind shear and low cloud. A topographical map of the Sydney Basin annotating specific locations used in this report has been provided in Figure 1.2.

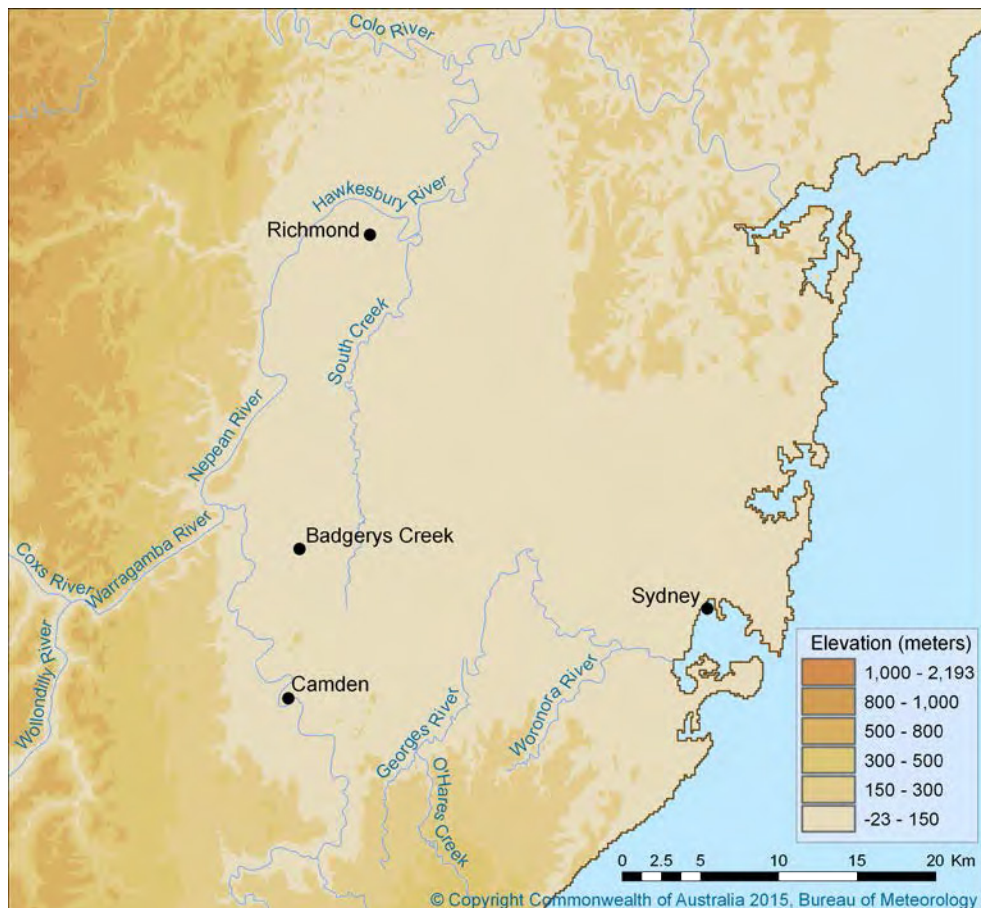


Figure 1.2 Topographical map of Sydney Basin

1.3 Department of Infrastructure and Regional Development

In 2014 the Bureau was engaged by the Australian Government Department of Infrastructure and Regional Development (DIRD) to provide a preliminary report surrounding the usability of the Badgerys Creek site for airport development on the basis of meteorology. The following report has been based on the proposed Option A airport master plan developed for the 1997-99 Second Sydney Airport Environmental Impact Statement provided in Figure 1.3.

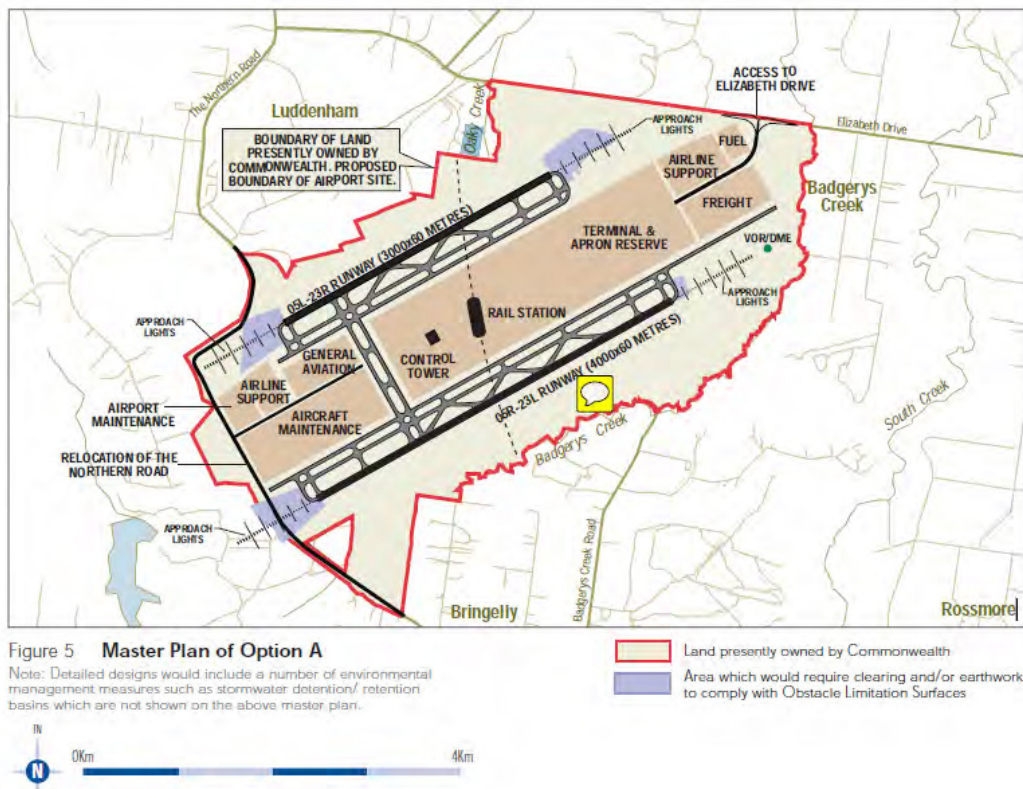


Figure 1.3 1997-99 EIS Master plan option A for WSA: The white balloon shows the current location of the Badgerys Creek AWS

The aim of the preliminary report is to provide a broad climatology of the area together with an analysis of weather effects on the usability of WSA; this will also provide DIRD with sufficient information for the determination of areas which may require further directed research.

1.4 Liability

While every effort is made to supply the best data available, this may not be possible in all cases. We do not give any warranty, nor accept any liability in relation to the information given, except that liability (if any), that is required by law.

2 Wind

Wind is the movement of air in the atmosphere. Wind speed and direction can directly affect the usability of an airport and the optimisation of air traffic services at that airport. Strong winds perpendicular to a runway can affect the ability of an aircraft to land safely. Strong winds parallel to a runway can also affect the landing of an aircraft by impacting their ability to use aviation navigational aids or by reducing air speed sufficiently to cause the aircraft to stall.

The AWS at Badgerys Creek which measures wind speed, wind direction and wind gust strength has been used for wind analysis in this section of the report.

2.1 Topographic wind effects

The local topography interacts with the flow of air and movement of air pollutants in numerous ways. Topography has the ability to influence wind by channelling flows through valleys and creating air movement due to air density imbalances and pressure gradients in otherwise calm conditions. Wind direction analysis confirms that local topography influences both wind speed and direction at Badgerys Creek.

2.1.1 Anabatic wind

During the daytime in calm sunny weather a mountain top may receive more warming from the sun than the land below. In this instance, the parcel of warm air rises and creates an area of low pressure at the top of the mountain. Wind from the bottom of the mountain will move upslope into the area of low pressure, called an upslope wind. This process is known as an anabatic effect. The anabatic effect at Badgerys Creek would have the effect of producing light easterly winds when otherwise calm conditions would have prevailed.

2.1.2 Katabatic wind

A katabatic wind, also called a drainage wind, occurs when air of higher density at higher elevation moves down slope under the force of gravity. Katabatic winds in the western Sydney basin often occur in the overnight period and into the early morning. The katabatic effect from the surrounding mountains at Badgerys Creek produces a wind which blows from the south-westerly direction. A more detailed wind study could be conducted to determine the source of the katabatic wind, however the katabatic wind at WSA would be expected to be light and therefore cause little operational impact.

2.1.3 Valley flows

Mountain and valley winds occur locally as a result of the differences in the heating and cooling of the air over the mountains and valleys. In the daytime valley winds blow up the valleys and mountain slopes and at night the mountain winds blow in the opposite direction. It is unclear at this stage whether valley flows affect the AWS site at Badgerys Creek. A more detailed wind study could be conducted to determine the occurrence of valley flows, however valley flows would be expected to be light and therefore cause little operational impact to WSA.

2.2 Wind speed and direction

Wind directions are measured relative to true north such that the wind blows from the specified direction, and are measured in knots. The wind data analysed for Badgerys Creek¹ was a 10 minute average wind speed and direction.

Data has been displayed using a wind rose. The wind rose illustrates the main 8 wind directions and attributes a percentage occurrence of winds within a set speed range. The addition of the different speed ranges in one direction makes up one 'arm' of the wind rose. Figure 2.1 illustrates the four seasonal wind roses for Badgerys Creek.

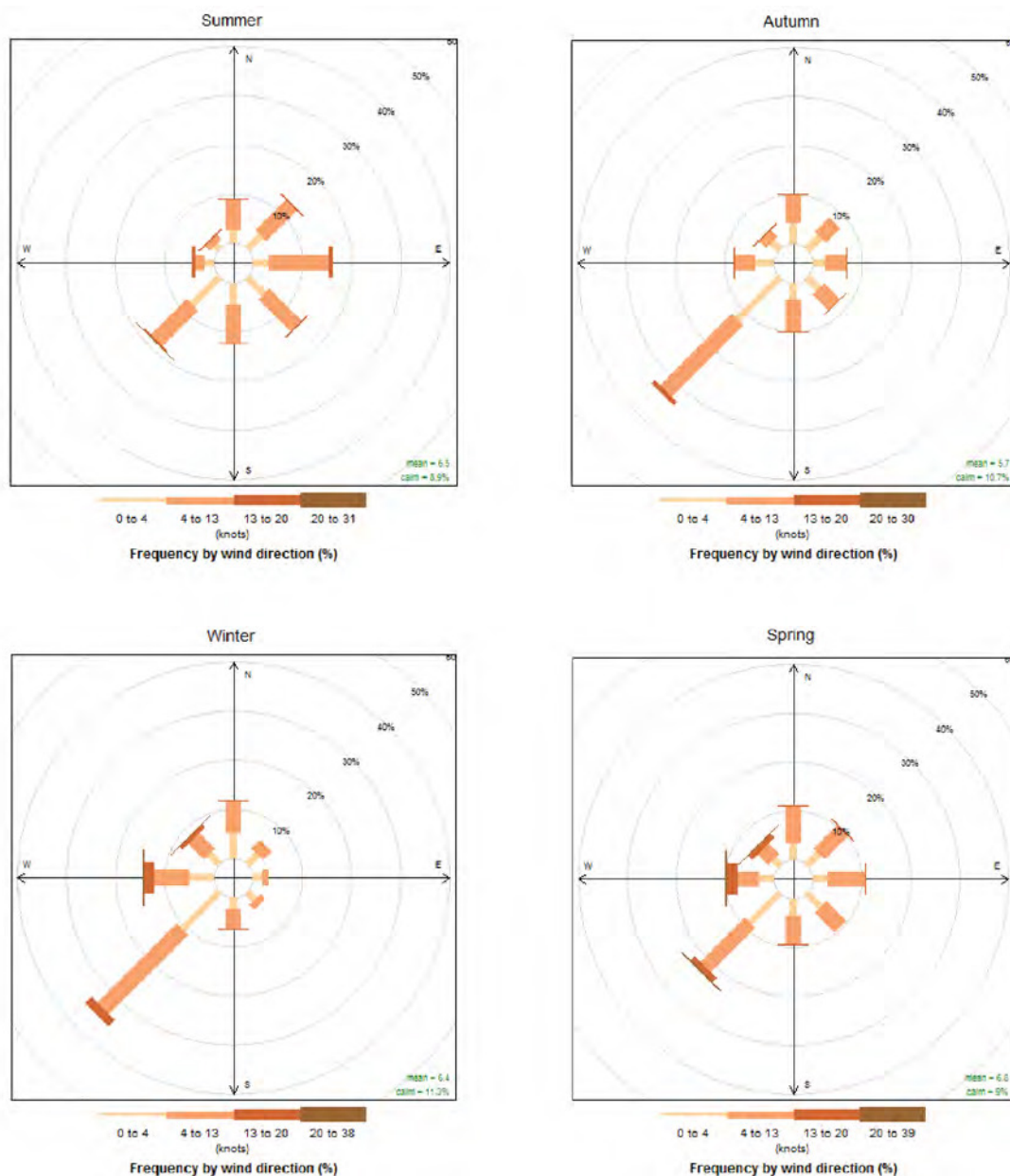


Figure 2.1 Seasonal wind rose for Badgerys Creek

¹ Unless otherwise stated the 10 minute data for Badgerys Creek was extracted from 4 Dec 1998 to 18 Nov 2014.

2.2.1 Summer and autumn

With a belt of high pressure to the south of the continent easterly winds prevail for much of the summer period. The Sydney Basin usually experiences an afternoon north-easterly sea-breeze along the coast tending more easterly as it moves further inland. As the heat of the day dissipates a south-westerly katabatic develops at Badgerys Creek overnight. The progression of a trough through the area can produce a more northerly or southerly component to the wind depending on the location of the associated area of low pressure. Furthermore, thunderstorms can create localised fluctuations in wind from any direction.

During summer the winds from the south-west are most common at Badgerys Creek. Yet winds from the eastern sector are also frequent and at their strongest during summer.

Winds in autumn are weaker from all directions except for the southwest. South-westerly winds predominate in autumn occurring more than 20% of the time. From summer to autumn there is a shift in frequency of winds from the easterly quadrant to the westerly quadrant.

2.2.2 Winter and spring

In winter the belt of high pressure is over the middle of the continent producing light and variable winds and fog conditions in the western Sydney Basin. The approach of cold fronts and associated troughs from the west brings synoptic westerly conditions. It is common for surface frontal troughs to be affected by the Great Dividing Range, modifying their trajectory and causing a southerly change to propagate along the NSW coastline.

During winter winds are infrequent from the easterly quadrant. Instead more than 30% of wind is expected to occur from the south-westerly direction. Winter into spring shows a shift back from a westerly wind regime into more easterly winds.

In spring winds from the south-west begin to weaken and an increase in wind strength occurs from the eastern sector. Additionally easterly winds become more frequent.

The wind rose in all seasons shows that winds from west to north-westerly directions are effectively blocked due to topography.

2.3 Percentage wind frequency table

30-minute data² has been analysed for all months of the year to determine the percentage occurrence for wind speed and direction at Badgerys Creek (refer to Table 2-1).

² Data range for Table 2-1 encompasses 10 Jan 1996 to 10 Dec 2014.

Table 2-1 Table of percentage occurrence for selected wind direction and speed categories

Wind	Wind Speed (knots)												
	Calm	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	>50	Total (%)
Calm	10.0												10.0
360		1.4	1.2	0.2	* ³	*	0.0	0.0	0.0	0.0	0.0	0.0	2.8
010		1.3	1.3	0.2	*	*	0.0	0.0	0.0	0.0	0.0	*	2.9
020		1.2	1.2	0.2	*	*	0.0	0.0	0.0	0.0	0.0	0.0	2.7
030		1.2	1.0	0.1	*	*	0.0	0.0	0.0	0.0	0.0	0.0	2.3
040		1.0	0.7	0.1	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
050		1.1	0.8	0.1	*	*	0.0	0.0	0.0	0.0	0.0	0.0	2.0
060		0.9	0.8	0.2	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
070		0.9	0.9	0.3	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
080		0.7	0.8	0.4	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
090		0.7	0.9	0.5	*	*	0.0	0.0	0.0	0.0	0.0	0.0	2.2
100		0.8	0.9	0.4	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
110		1.0	0.9	0.3	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
120		0.9	0.8	0.2	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
130		1.1	0.8	0.2	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
140		1.0	0.7	0.2	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
150		1.0	0.6	0.2	*	*	0.0	0.0	0.0	0.0	0.0	0.0	1.9
160		0.9	0.6	0.2	*	*	*	0.0	0.0	0.0	0.0	0.0	1.7
170		1.1	0.8	0.2	*	*	*	0.0	0.0	0.0	0.0	0.0	2.2
180		1.0	0.9	0.2	*	*	0.0	0.0	0.0	0.0	0.0	0.0	2.1
190		1.1	1.0	0.3	*	*	0.0	0.0	0.0	0.0	0.0	0.0	2.4
200		1.2	1.1	0.3	0.1	*	0.0	0.0	0.0	0.0	0.0	0.0	2.6
210		1.6	1.3	0.4	0.1	*	0.0	0.0	0.0	0.0	0.0	0.0	3.4
220		2.6	2.1	0.6	0.1	*	*	*	0.0	0.0	0.0	0.0	5.5
230		4.9	3.6	0.7	0.1	*	*	*	0.0	0.0	0.0	0.0	9.3
240		4.4	2.4	0.6	0.2	*	*	0.0	*	0.0	0.0	0.0	7.5
250		2.3	1.1	0.6	0.2	*	*	*	*	0.0	0.0	0.0	4.3
260		1.0	0.6	0.4	0.2	*	*	*	0.0	0.0	0.0	0.0	2.2
270		0.8	0.4	0.3	0.2	*	*	0.0	0.0	0.0	0.0	0.0	1.7
280		0.6	0.3	0.3	0.2	*	*	*	0.0	0.0	0.0	0.0	1.4
290		0.5	0.4	0.3	0.2	*	*	*	0.0	0.0	0.0	0.0	1.4
300		0.5	0.4	0.2	0.1	*	*	0.0	0.0	0.0	0.0	0.0	1.3
310		0.6	0.4	0.2	0.1	*	*	*	0.0	0.0	0.0	0.0	1.3
320		0.5	0.3	0.1	*	*	*	0.0	0.0	0.0	0.0	0.0	1.1
330		0.7	0.4	0.1	*	*	*	0.0	0.0	0.0	0.0	0.0	1.1
340		0.7	0.4	0.1	*	*	*	0.0	0.0	0.0	0.0	0.0	1.2
350		0.9	0.6	0.1	*	*	*	0.0	0.0	*	0.0	0.0	1.7
Total (%)	10.0	44.4	33.5	9.8	2.0	0.3	*	*	*	*	0.0	*	

³ An asterisk indicates the event has occurred but with a frequency less than 0.05%.

Table 2-1 provides the ability to estimate the percentage chance of obtaining a specific direction above a certain speed based on climatology. It can be seen from the table that the wind at Badgerys Creek is calm⁴ 10% of the time; Winds from the north and east almost never exceed 25kts; Winds exceeding 30kts from the south and west can be expected infrequently.

2.4 Wind gusts

Wind gusts are noted as the highest maximum 3 second gust in the last 10 minutes. The direction associated with a recorded wind gust is the average 10 minute wind direction which may not be indicative of the direction from which the gust came from. Nevertheless, anecdotal evidence suggests that the majority of wind gusts come from the recorded wind direction. A wind rose⁵ of gusts has been created in Figure 2.2.

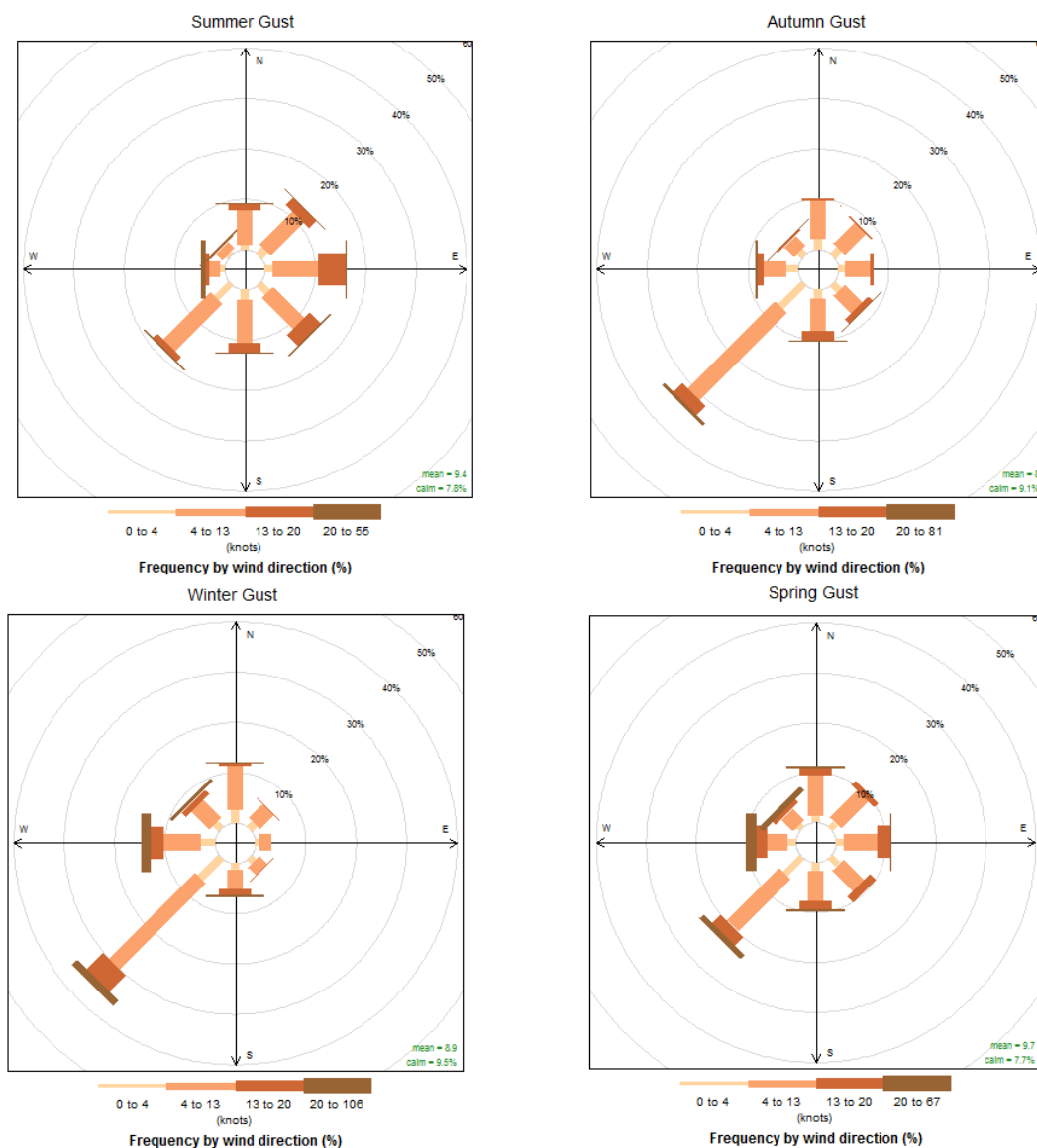


Figure 2.2 Seasonal wind gust rose for Badgerys Creek

⁴ Calm has been defined as 0kts for this report.

⁵ Refer to section 2.2 for instructions on how a wind rose is constructed.

2.4.1 Summer and autumn

Gusts in summer and autumn often occur from thunderstorms and synoptically reinforced sea breezes. The wind roses show that wind gusts in summer and autumn can occur from any direction, although wind gusts from west and north-west is not very common. Due to the blocking effect of the Great Dividing Range it could be assumed that thunderstorms are typically responsible for the gusts from the west and northwest directions.

The predominant gust direction appears to be south-westerly with more than 20% of gusts coming from this direction. However gusts equal to or greater than 12kts occur most frequently from the east.

2.4.2 Winter and spring

Wind gusts in winter and spring occur in a similar direction and frequency as those in summer and autumn, however to a lesser magnitude.

2.5 Runway nomination

CASA rules covering the maximum cross-wind and downwind limits for runway selections state:

‘CASA determined that air traffic control should not nominate runways for use if an alternative runway is available when:

- For runways that are completely dry, the cross-wind component, including gusts, exceeds 20 knots; and the downwind⁶ component, including gusts, exceeds 5 knots.*
- For runways that are not completely dry, the cross-wind⁷ component, including gusts, exceeds 20 knots; and there is any downwind component.’*

Thus, wind strength and direction can directly influence the availability of different runway configurations.

10-minute data was extracted from both Badgerys Creek and Sydney KSA⁸ to complete the crosswind and headwind analysis. It is important to note that the data set for Badgerys Creek is not as extensive as that for Sydney KSA and may not be truly representative of climatic conditions.

2.5.1 Crosswind

A crosswind is a wind perpendicular to the direction of runway orientation. Generally, lighter aircraft find it more difficult to compensate for a crosswind on landing and take-off.

Calculations have been based on initial information detailing a runway in the direction of 05/23 true. Calculations can be reconfigured as required. Runway 16/34 at Sydney

⁶ Downwind is defined as the wind's force on an aircraft in the same direction with which the wind is blowing, also known as a tailwind.

⁷ Crosswind is defined as the wind's force perpendicular to the course of an aircraft.

⁸ Unless otherwise stated the 10 minute data for Sydney KSA was extracted from 10 Oct 1948 to 18 Nov 2014.

KSA has been converted to degrees true for wind calculations. The mean 10-minute wind speed has been used for cross-wind calculations.

The number of days per month in which the crosswind would be expected to exceed 20kts at WSA and Sydney KSA has been graphed in Figure 2.3.

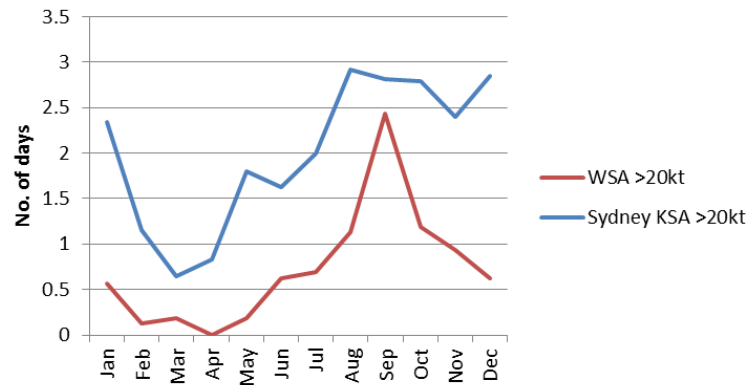


Figure 2.3 Average number of days per month of crosswind >20kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34

Crosswind of >20kts would occur on average on more than one day per month in August, September and October at WSA. In comparison, on average Sydney KSA would experience crosswinds of >20kts in all months except March and April.

A climatology of available data has recorded 9 in 722 cases in which a crosswind of >20kts would have occurred from the southeast at WSA. The potential for a south-easterly wind to cause a crosswind on runway 05/23 would be very rare; however a longer climatic record at Badgerys Creek would provide greater detail. Synoptic situations in which this event could occur would likely be restricted to gusts eventuating from a thunderstorm, or the positioning of an East Coast Low off the NSW coast. A summary table of historical crosswind direction has been supplied in Table 2-2.

Table 2-2 Table of historical percentage direction of crosswind >20kts

	WSA	Sydney KSA
	>20kts	>20kts
South-easterly crosswind	1.2%	14.8%
North-westerly crosswind	98.8%	85.2%

The number of days per month in which the crosswind would be expected to exceed 25kts at WSA and Sydney KSA has been graphed in Figure 2.4.

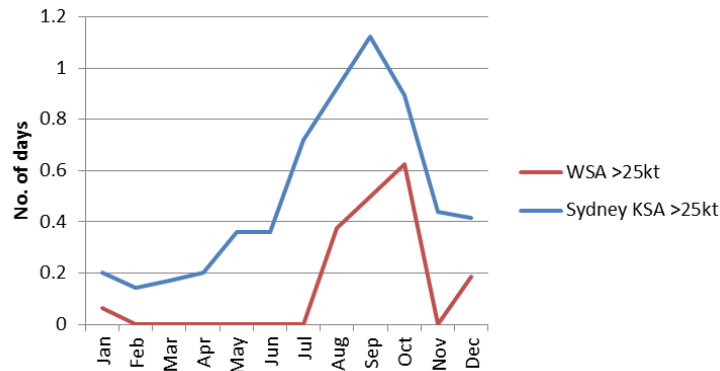


Figure 2.4 Average number of days per month of crosswind >25kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34

Crosswind of >25kts is expected to occur on average on more than 0.5 days per month in October at WSA. In comparison, Sydney KSA experiences crosswinds on runway 16/34 of >25kts on more than 0.5 days per month from July to October.

There are no historical cases to date in which a crosswind of >25kts would have occurred from the southeast at WSA; however a longer climatic record at Badgerys Creek would provide greater detail. A summary table of crosswind direction has been supplied below (refer to Table 2-3).

Table 2-3 Table of historical percentage direction of crosswind >25kts

	WSA	Sydney KSA
	>25kts	>25kts
South-easterly crosswind	0.0%	6.3%
North-westerly crosswind	100.0%	93.7%

The number of days per month in which the crosswind would be expected to exceed 30kts at WSA and Sydney KSA has been graphed in Figure 2.5.

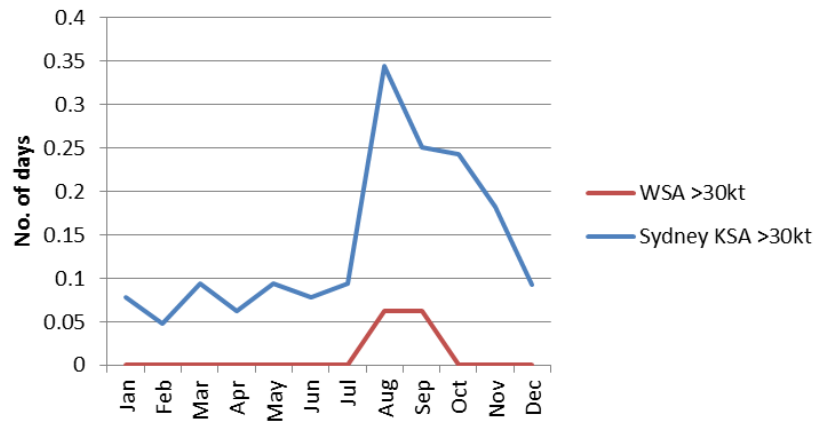


Figure 2.5 Average number of days per month of crosswind >30kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34

Crosswind of >30kts would be rare at WSA but are possible from the north-westerly wind direction. In comparison, Sydney KSA experiences crosswinds on runway 16/34 of >30kts on average on more than 0.5 days per month from August to November.

Historically there is yet to be an instance in which a crosswind of >30kts from the south-east that would impact on the 05/23 runway at WSA; however a longer climatic record at Badgerys Creek would provide greater detail. A summary table of crosswind direction has been supplied below (refer to Table 2-4)

Table 2-4 Table of percentage direction of crosswind >30kts

	WSA	Sydney KSA
	>30kts	>30kts
South-easterly crosswind	0.0%	13.2%
North-westerly crosswind	100.0%	86.8%

2.5.2 Headwind

A head-wind is a wind parallel but in the opposing direction to an aircraft landing or taking-off on the runway. At lower speeds a headwind is most beneficial for aircraft both landing and taking-off. Strong headwinds can impact an aircraft's use of approach instrumentation, or in extreme cases can cause the aircraft to lose sufficient air speed resulting in an engine stall.

The number of days per month in which the headwind would be expected to exceed 25kts at WSA and Sydney KSA has been graphed in Figure 2.6.

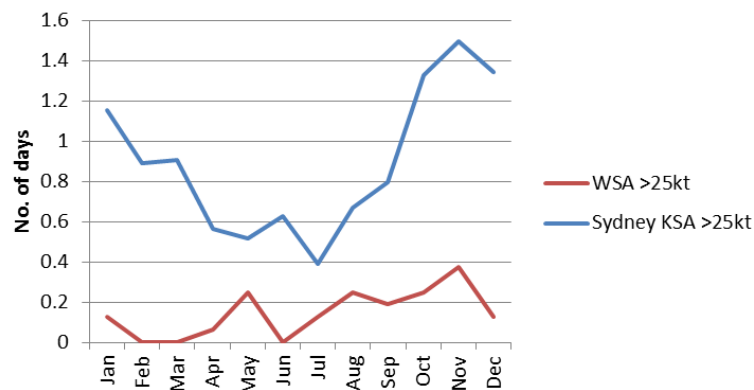


Figure 2.6 Average number of days per month of headwind >25kts expected at WSA on runway 05/23 and Sydney KSA on runway 16/34

Headwind of >25kts could occur in almost any month of the year at WSA, but would be rare. Headwinds in excess of 25kts are commonly seen at Sydney KSA where they occur approximately one day per month from October to January.

There is not historical data to date where a headwind exceeding 25kts would have impacted WSA on Runway 23; however a longer climatic record at Badgerys Creek would provide greater detail. A summary table of headwind direction has been supplied below (refer to Table 2-5).

Table 2-5 Table of percentage direction of headwind >25kts

	WSA	Sydney KSA
	>25kts	>25kts
North-easterly headwind	0.0%	4.3%
South-westerly headwind	100.0%	95.7%

The number of days per month in which the headwind exceeds 30kts at WSA and Sydney KSA has been graphed in Figure 2.7.

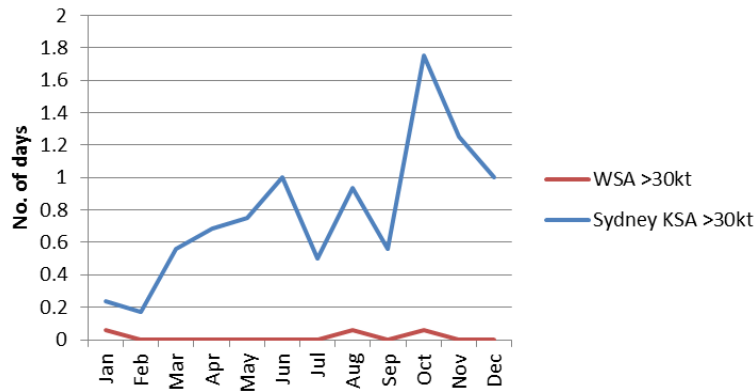


Figure 2.7 Average no. of days per month of headwind >30kts on WSA runway 05/23 and Sydney KSA runway 16/34

Although it is possible to see a headwind exceed 30kts at WSA it is extremely rare. However, headwinds in excess of 30kts occur at Sydney KSA on one day a month in June and on more than one day a month from October to December.

There is not historical data to date where a headwind exceeding 30kts would have impacted WSA on Runway 23; however a longer climatic record at Badgerys Creek would provide more detail. A summary table of headwind direction has been supplied below (refer to Table 2-6)

Table 2-6 Table of percentage direction of headwind >30kts

	WSA	Sydney KSA
	>30kts	>30kts
North-easterly headwind	0.0%	6.9%
South-westerly headwind	100.0%	93.1%

2.6 Discussion

Topographical wind effects are common at Badgerys Creek due to the proximity of the site to the Great Dividing Range. It is unclear if anabatic winds or valley flows affect the site from the preliminary data but neither wind would be expected to be significantly strong to impact on operations at WSA. However, it is clear from both the data and anecdotal evidence that a south-westerly katabatic wind commonly occurs overnight.

Winds from the south-west are common throughout the year but are most frequent during winter. The remaining winds have a more easterly or westerly component to the wind depending on the season. Easterly winds become more frequent during late winter and strengthen into spring. Winds from the eastern sector weaken during summer shifting to the west during autumn and remaining through much of winter.

The wind in all seasons is effectively blocked by topography from the west to north-westerly directions.

The WSA site would likely be less susceptible to both crosswind and headwind effects than Sydney KSA. The months of August to October are the most probable times to experience a crosswind exceeding 20kts at WSA, with the majority of crosswind events occurring from the southwest. In comparison, WSA would be expected to experience crosswind effects on average half as often as Sydney KSA.

There appears to be a threshold (approximately 20-25kts) in which the north-westerly synoptic winds are sufficiently strong to overcome the terrain and produce a crosswind at WSA.

Headwinds in excess of 25kts would be rare at WSA but could occur in almost any month of the year. Sydney KSA is approximately 4 times more likely to experience headwinds on the parallel runways (16/34) than WSA is on runway 05/23.

It is important to note that the clearance of vegetation and the erection of buildings can cause changes in wind speed and direction. Removal of vegetation is likely to cause a reduction in surface drag resulting in slightly stronger wind speeds than would have occurred otherwise. The effect may be more pronounced at the base of the lee side of the Great Dividing Range.

Recommendation 1: Clearance of vegetation to the west and south-west direction of the airport should be avoided as reducing drag may cause increases in wind speeds from downslope winds.

The erection of buildings such as a terminal has the ability to effect air movement around an airport. Obstacles such as buildings have the ability to redirect air flow around surfaces creating effects such as funnelling, lift and turbulence. Generally obstacles with a large surface area relative to the wind direction would have greater impact on air flow. Therefore orientating obstacles with large surface areas towards directions of greatest wind strength, such as the west, would not be recommended.

Recommendation 2: Orientation of buildings containing large surface areas should avoid the direction of strongest wind (westerly sector) as much as possible to avoid creating turbulent effects.

3 Temperature

Instruments measuring temperature are located at the Badgerys Creek AWS site. The equipment is housed within a Stevenson screen at a height of approximately 1.2m above the ground. Whilst average daily temperatures are important it is the extremes in heat or cold that can impact airport optimisation.

3.1 Mesoscale effects

Topography has the ability to affect temperature via both elevation and air movement. The AWS site at Badgerys Creek is only 81.2m above sea level producing negligible effects on temperature due to elevation. However, air movement around Badgerys Creek has the ability to affect temperatures at the site.

3.1.1 Coastal effects

Usually coastal locations see less temperature variability due to their proximity to the ocean. Ocean temperatures fluctuate slightly throughout the year but considerably less than the land surface. The ocean is a great moderator of air temperature in coastal locations. This results in milder nights and days.

Badgerys Creek experiences very limited temperature moderation from coastal influences; however the sea breeze has the potential to reach Badgerys Creek during the late afternoon producing cooler apparent temperatures during summer and early autumn. Otherwise, it is common to see larger daily fluctuations in temperature from sites in the western Sydney Basin.

3.1.2 Foehn effect

It is common to see precipitation triggered by orographic uplift on a mountain range such as the Great Dividing Range to the west of Badgerys Creek. Air reaching the top of the ridge cools to produce condensation by way of cloud or rainfall, and then continues as a dry air mass down the leeward side of the mountain. The air moving down the leeward side of the mountain warms at a rate faster than the surrounding environment causing an artificial increase in temperature.

Badgerys Creek lies at the bottom of the Great Dividing Range where it would be possible to see artificially high temperatures during the thunderstorm season, especially from November to March.

3.2 Temperature climatology

Table 3-1 below summarises the climatology of the temperature at Badgerys Creek since the site opened in October of 1995.

Table 3-1 Temperature climatology for Badgerys Creek

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean daily maximum temperature (°C)	29.9	28.5	26.7	23.9	20.6	17.8	17.3	19.3	22.7	24.7	26.1	28.1
Highest temperature (°C)	45.8	42.6	40.0	34.6	27.9	25.2	25.4	28.8	34.8	37.2	41.9	42.5
Mean daily minimum temperature (°C)	16.9	17.1	15.1	11.3	7.6	5.4	4.2	4.6	7.7	10.2	13.4	15.2
Lowest temperature (°C)	8.2	8.5	6.4	-0.1	-1.1	-3.0	-4.5	-1.9	-0.5	2.2	5.3	6.6

January at Badgerys Creek is the hottest month with an average temperature of 29.9°C. The highest temperature ever recorded at the site was 45.8 °C on 18th January 2013. Badgerys Creek has experienced temperatures exceeding 40°C in the months of November to March.

3.3 Temperature extremes

The average number of days a month in which the temperature: exceeds 30°C, exceeds 35°C, or falls below 0°C has been supplied in Table 3-2.

Table 3-2 Temperature climatology extremes for Badgerys Creek

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Number of Days over 30°C	13.4	9.6	4.8	0.8	nil	nil	nil	nil	1.7	5.1	6.8	10.2
Mean Number of Days over 35 °C	5.2	2.6	0.5	nil	nil	nil	nil	nil	nil	0.8	1.8	2.8
Mean Number of Days below 0 °C	nil	nil	nil	0.1	0.3	2.0	3.3	2.1	0.2	nil	nil	nil

The month of January has the most days on average above 30°C and 35°C with 13.4 and 5.2 days respectively. July has the most number of days on average below 0 °C with 3.3 days.

3.4 High temperatures

High temperatures have the ability to alter the optimum usability of an airport. Temperature has an indirect relationship with air density. As temperature climbs the air becomes less dense and affects aero-dynamical lift. Perhaps more significant is the effect of temperatures on fuel. High temperatures cause fuel to expand restricting the capacity to adequately refuel aircraft in some cases. Temperatures exceeding the flash point for jet fuel (Jet A/A1), approximately 38 °C, are extremely important as liquid becomes a gas.

The average number of hours per month in which the temperature becomes exceedingly high, and the time of day at which these high temperatures are most likely has been supplied in section 3.4.1 to 3.4.3.

3.4.1 Temperatures exceeding 30°C

The number of hours a month in which the temperature was greater than or equal to 30° at Badgerys Creek has been graphed in Figure 3.1.

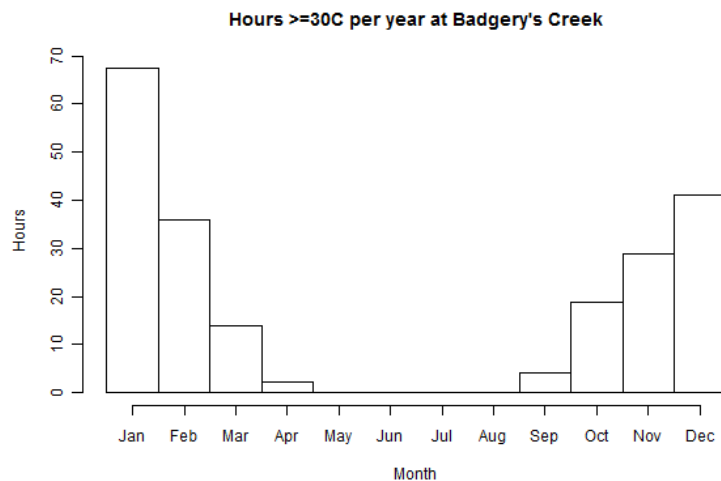


Figure 3.1 Average hours of temperature $\geq 30^{\circ}\text{C}$ at Badgerys Creek

The bar graph shows that the temperature is equal to or greater than 30°C regularly throughout the end of spring, summer and the start of autumn at Badgerys Creek. A boxplot of the average hourly occurrence of temperatures exceeding 30°C has been provided in Figure 3.2.

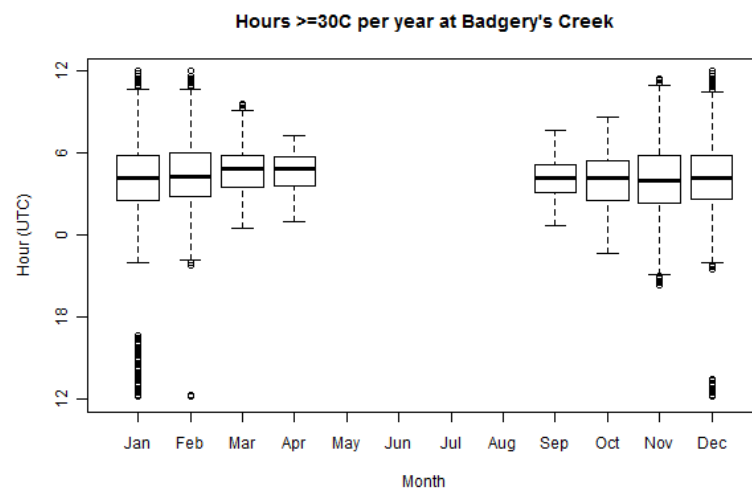


Figure 3.2 Boxplot⁹ of average hourly occurrence of temperature exceeding 30°C at Badgerys Creek

When the temperature exceeds 30° at Badgerys Creek, it is most commonly during middle to late afternoon.

⁹ Boxplots display the median as a solid line. The box represents the first to third quartile (25-75%) of data. The lines extending from the box indicate the variability outside the first and third quartile. Additional points plotted are outliers in the data.

3.4.2 Temperatures exceeding 35°C

The number of hours a month in which the temperature was greater than or equal to 35°C has been graphed in Figure 3.3.

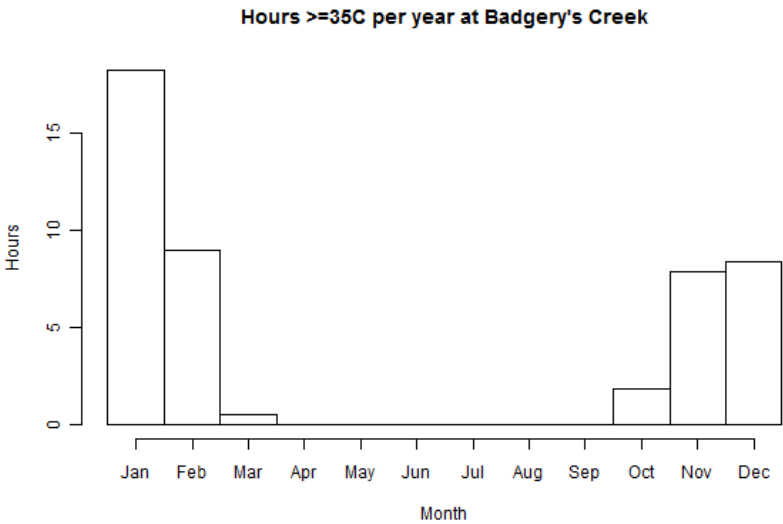


Figure 3.3 Average hours of temperature ≥ 35°C at Badgerys Creek

The graph shows that it is not unusual to see temperatures exceed 35°C in late spring and summer at Badgerys Creek. A boxplot of the average hourly occurrence of temperatures exceeding 35°C has been provided in Figure 3.4.

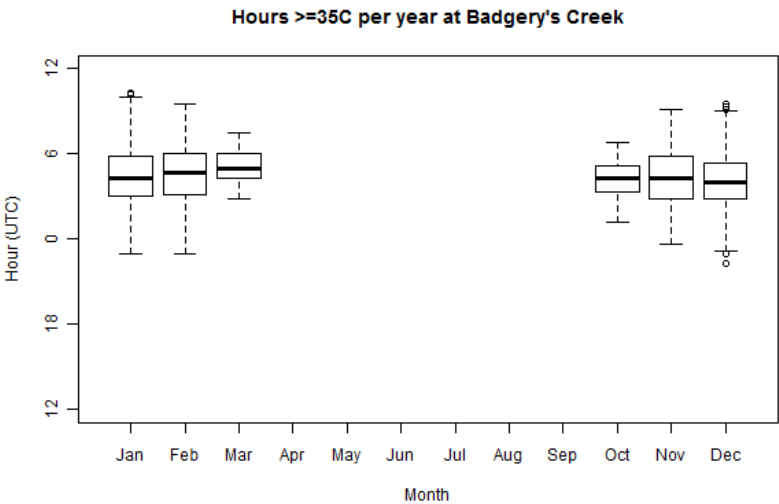


Figure 3.4 Boxplot of average hourly occurrence of temperature ≥ 35° at Badgerys Creek

On the days that the temperature does exceed 35°C, it is middle to late afternoon when this is most likely to occur.

3.4.3 Temperatures exceeding 40°C

The number of hours a month in which the temperature $\geq 40^{\circ}\text{C}$ has been graphed in Figure 3.5.

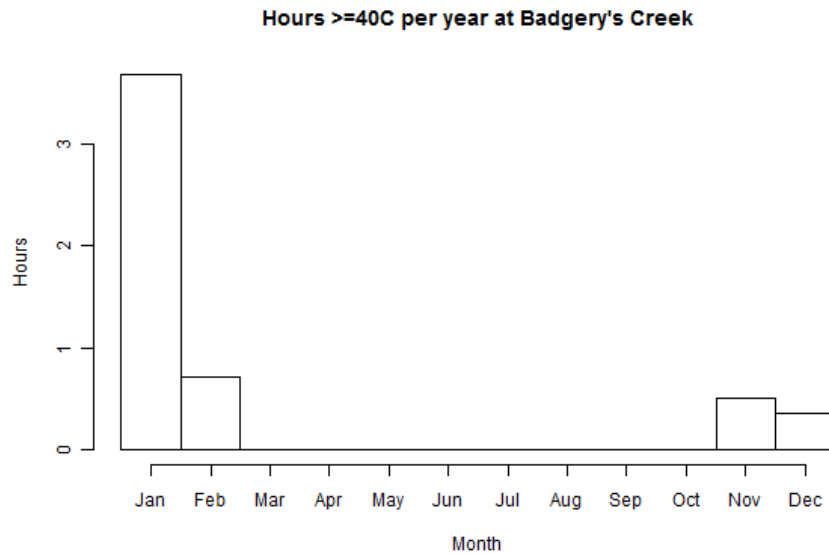


Figure 3.5 Average hours of temperature $\geq 40^{\circ}\text{C}$ at Badgerys Creek

It can be seen that whilst it is possible to see temperatures exceed 40°C in late spring and summer it is not common. The month in which temperatures are most likely to exceed 40°C is January, where there is an average of 3-4 hours a month. A boxplot of the average hourly occurrence of temperatures exceeding 40°C has been provided in Figure 3.6.

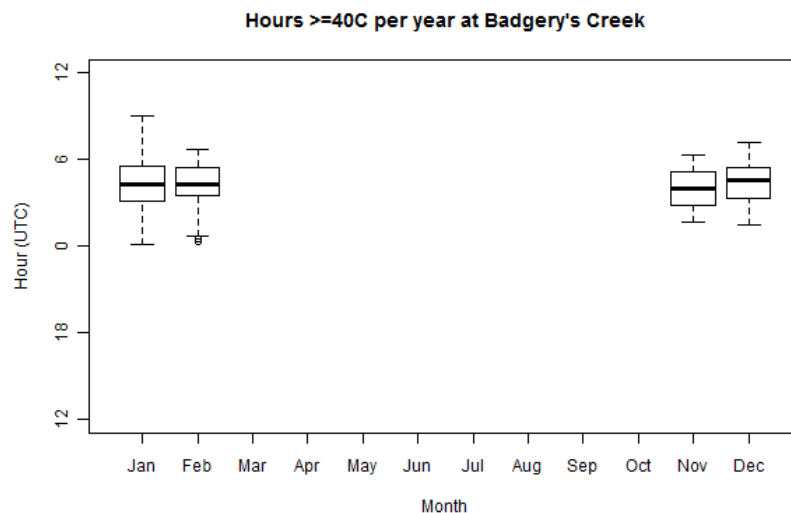


Figure 3.6 Boxplot of average hourly occurrence of temperature $\geq 40^{\circ}$ at Badgerys Creek

On the days that the temperature is equal to or greater than 40°C the time of day is generally middle to late afternoon.

3.5 Low temperatures

Temperatures below zero at surface level have the ability to produce adverse weather phenomena for aircraft including hail, snow, sleet, frost, icing and freezing fog.

3.5.1 Temperatures below 0°C

The number of hours a month in which the temperature $\leq 0^{\circ}\text{C}$ has been graphed in Figure 3.7.

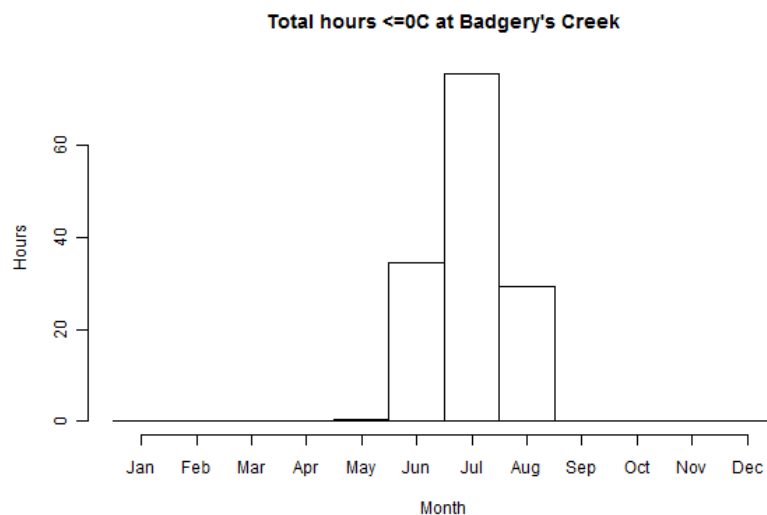


Figure 3.7 Average hours of temperature $\leq 0^{\circ}$ at Badgerys Creek

It appears common for temperatures to drop below zero in the months from June to August at Badgerys Creek. Temperatures are most likely to drop below 0°C in July, where there is in average of more than 75 hours a month. A boxplot of the average hourly occurrence of temperatures below 0°C has been provided in Figure 3.8.

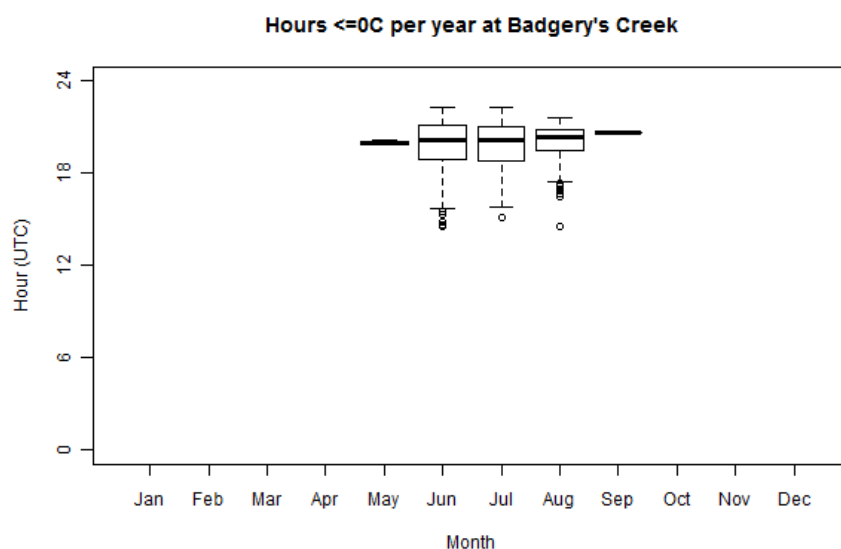


Figure 3.8 Hourly occurrence of temperatures $\leq 0^{\circ}$ at Badgerys Creek

The early morning period prior to sunrise is the most common time for temperatures to be recorded below zero at Badgerys Creek.

3.5.2 Frost

Frost and ice accumulation on ground surfaces can occur at temperatures below zero. Data with a temperature of below zero¹⁰ has been analysed to indicate the potential for frost at Badgerys Creek (refer to Figure 3.9). For comparison, data has also been extracted for Canberra Airport in Figure 3.10.

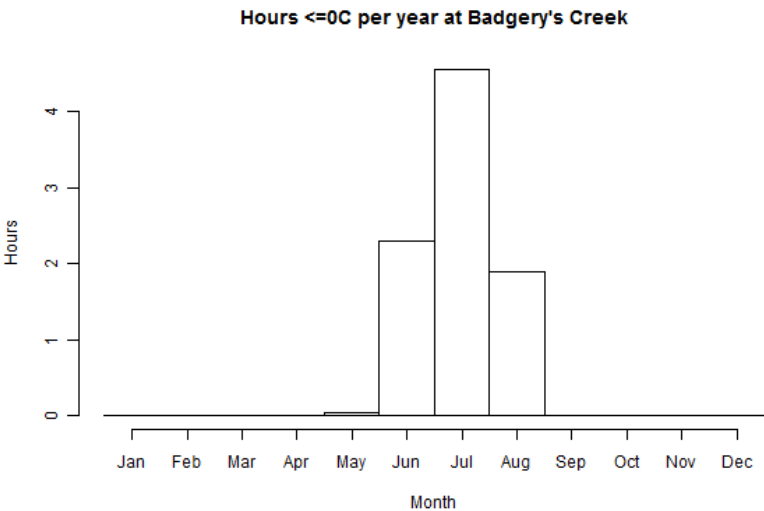


Figure 3.9 Average hourly inferred frost occurrence at Badgerys Creek

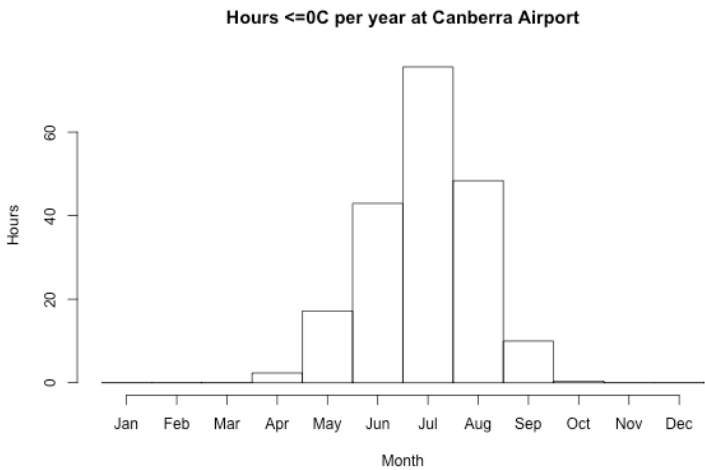


Figure 3.10 Average hourly inferred frost occurrence at Canberra Airport

Frost could potentially form between the months of May to August at Badgerys Creek. Frost is mostly likely to occur in July with over four hours on average expected at WSA. In comparison, From April to September Canberra Airport has approximately 20 times more hours of frost occurrence than Badgerys Creek.

¹⁰ Temperatures below zero degrees at the site of the instrument approximately 1.2m height. Grass temperatures are not currently available at Badgerys Creek.

The hours of the day in which frost conditions are most likely at Badgerys Creek and Canberra Airport have been plotted in Figure 3.11 and Figure 3.12.

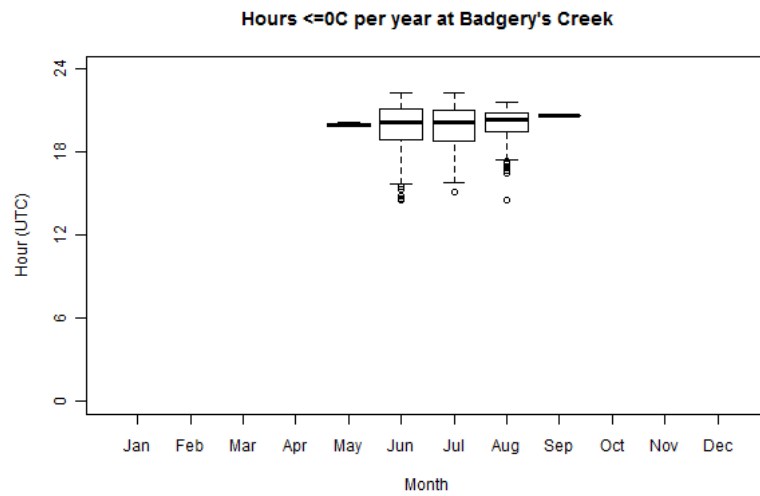


Figure 3.11 Hourly inferred frost occurrence at Badgerys Creek

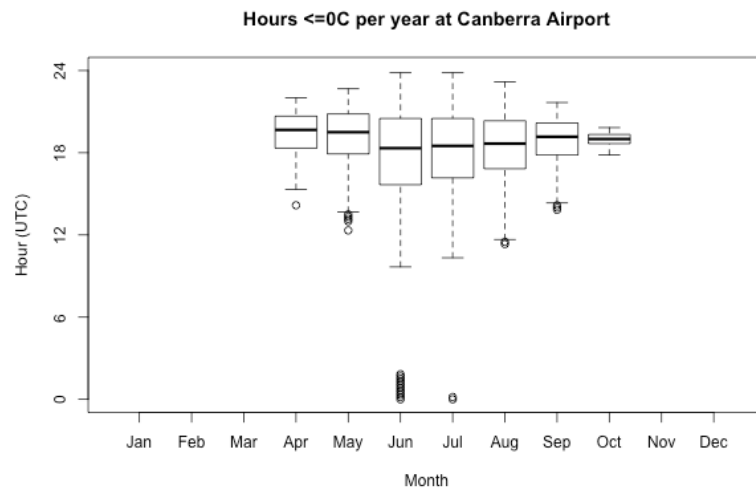


Figure 3.12 Hourly inferred frost occurrence at Canberra Airport

Frost is most likely to occur from May to September with the most frequent time of day being near sunrise at Badgerys Creek. The potential for frost at Canberra Airport extends from April to October where conditions exist from the early morning until mid-morning.

3.6 Freezing fog

Conditions are conducive to the formation of freezing fog when the temperature is below zero and the relative humidity is greater than or equal to 95%. In this circumstance the density of super-cooled liquid water suspended in the air would be significantly high enough to potentially cause rime icing on an aircraft's surface whose temperature is below zero. These atmospheric conditions also provide the ability for black ice to form on the tarmac, especially after rain.

The 10-minute data from Badgerys Creek AWS from 1999 to 2013 has been used to estimate the frequency of freezing fog (Figure 3.13). For comparison the annual average statistics for Canberra Airport have also been supplied in Figure 3.14.

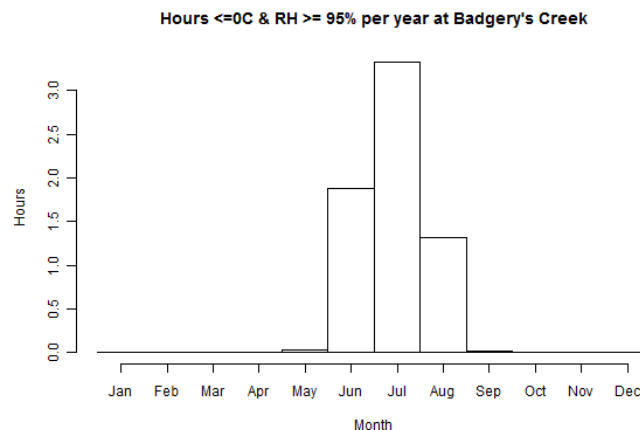


Figure 3.13 Average hours of inferred freezing fog occurrence at Badgerys Creek

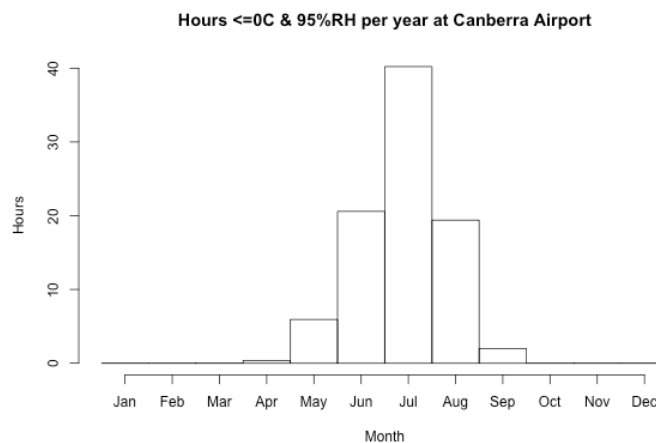


Figure 3.14 Average hours of inferred freezing fog occurrence at Canberra Airport

Conditions conducive to freezing fog could potentially occur annually in the months of May to September at WSA; however it is more common from June to August. On average there is 3.5hrs in July in which icing may impact surfaces at WSA. In comparison, Canberra Airport experiences on average 10 times more hours a month of freezing fog conditions during the winter months.

The hours of the day which may produce an icing problem have been plotted for Badgerys Creek and Canberra Airport in Figure 3.15 and Figure 3.16 respectively.

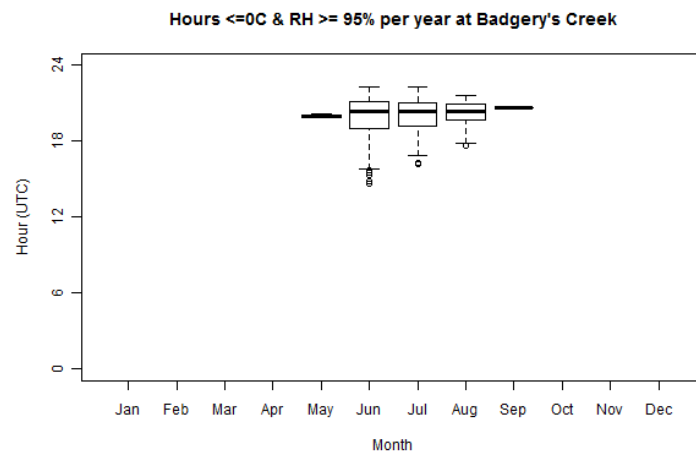


Figure 3.15 Hourly inferred freezing fog occurrence at Badgerys Creek

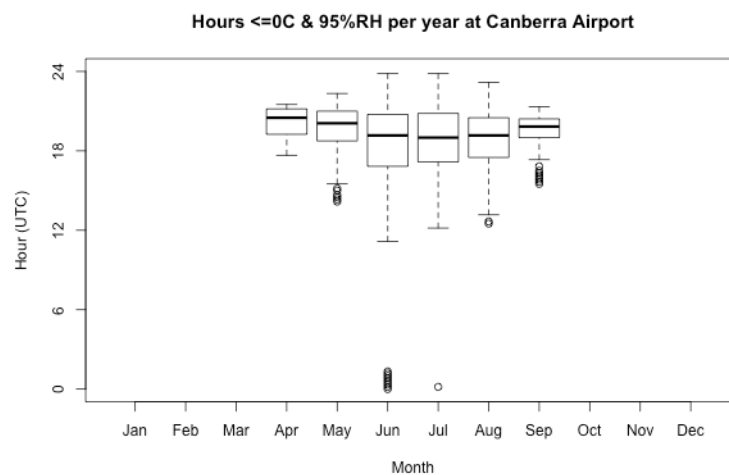


Figure 3.16 Hourly inferred freezing fog occurrence at Canberra Airport

Freezing fog would most commonly occur in the hours surrounding sunrise during the winter months at WSA. It would be possible, though rare, for events to initiate in the early morning hours. Freezing fog conditions at Canberra Airport are most probable in the early hours of the morning in winter and can extend until mid-morning in the worst of cases.

Conditions conducive to freezing fog could occur over short periods in the early morning hours at WSA. The availability of de-icing equipment at an airport can mitigate the impact of icing on an airframe.

3.7 Temperature inversions

A temperature inversion occurs when there is an increase in temperature with height above a location. The atmosphere beneath the inversion forms a stable layer of cold air trapped by the warm air aloft. The time taken for a ground-based temperature inversion to be broken down is directly correlated to surface temperature. Temperature inversions tend to be more significant during the cooler months where the air at the

surface is cooler than the air aloft, and the ability of the surface to heat during the early morning is diminished.

The presence of a temperature inversion has a significant influence on the ability of the atmosphere to disperse pollutants. An inversion layer effectively forms a barrier or 'lid' on the air in the lower atmosphere which restricts the mixing of air, and causes a build-up in pollutants. Pollutants from the previous day and those advected overnight into the area can be trapped by the inversion causing morning pollution problems. Generally, the concentration of pollutants in the air is strongest during the early morning hours when a low-level temperature inversion exists and wind speeds are light. Further study into inversion levels may be necessary for the calculation of pollution parameters.

3.8 Discussion

There appear to be two mesoscale effects affecting temperature at Badgerys Creek. The propagation of the sea breeze in the late afternoon into the western Sydney Basin has the ability to moderate temperatures. The sea breeze occurs frequently in the warmer months but may not always reach Badgerys Creek. On the other hand, the development of cloud and thunderstorms on the Great Dividing Range can contribute to anomalously high temperatures at WSA during the afternoon caused by a Foehn effect.

High temperatures ($\geq 35^{\circ}\text{C}$) primarily occur during the thunderstorm season from October to March. On the days that the temperature does exceed 35°C , it is middle to late afternoon when this is most likely to occur. Although temperatures above 35°C do not occur frequently they have ability to constrain fuel loading.

Recommendation 3: The effect of high temperatures may need to be considered during the construction of jet fuel facilities at WSA.

Low temperatures ($\leq 0^{\circ}\text{C}$) occur frequently in the months June to August at Badgerys Creek. On the days that the temperature is recorded below 0°C , it is the early morning before sunrise when this is most likely to occur.

The frequency of freezing fog and frost is low and generally restricted to the hours near sunrise. The statistics surrounding freezing fog suggest that there would be instances where icing could occur during the winter period. De-icing equipment has the ability to mitigate against the build-up of icing on an airframe.

Recommendation 4: De-icing equipment may need to be considered in order to optimise operations at WSA during periods of low temperature.

Further directed studies into surface temperature inversions are required to provide a comprehensive analysis on temperature inversions.

The development of WSA and associated development is expected to create microscale meteorological changes; however it is unclear as to whether the changes would be expected to be significant. For example, the removal of the grass surface and its replacement by tarmac will likely lead to a measurable increase in temperature at Badgerys Creek. It would be expected that the leading cause of temperature changes would be the construction of surfaces, such as the runway, taxiways, car parks, aprons and roads which have a higher thermal conductivity than the existing vegetation.

4 Rainfall

The usability of an airport can be affected by rainfall in many ways. Rainfall can affect aircraft landing distance, runway nomination and the type of approach due to poor visibility or low cloud. Additionally, heavy rainfall leading to flash flooding can affect aircraft operations by flooding taxiways and runways, damaging the runway, severely reducing tyre traction and in the worst case hydroplaning.

4.1 Rainfall climatology

Rainfall data for Badgerys Creek has been extracted to produce a statistical summary supplied in Table 4-1.¹¹

Table 4-1 Rainfall climatology for Badgerys Creek

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly Rainfall (mm)	77.4	108.0	77.3	43.2	40.1	52.1	23.0	35.9	33.9	52.7	74.5	63.6
Highest Monthly Rainfall (mm)	192.2	342.4	198.0	129.4	155.6	220.0	71.6	231.0	82.2	182.2	173.2	131.2
Lowest Monthly Rainfall (mm)	13.6	13.4	21.4	1.8	1.8	2.0	2.8	1.0	6.4	0.4	8.4	14.2
Highest Daily Rainfall (mm)	138.0	106.8	67.8	82.4	54.0	63.8	28.4	70.0	50.8	63.0	63.0	65.0

The average annual rainfall at Badgerys Creek is 680.9mm with rain recorded on average on 117.8 days per year. The monthly rainfall statistics contained within Table 4-1 have been graphed in Figure 4.1.

¹¹ Unless otherwise stated the data range used for rainfall comparison is Badgerys Creek – Oct 1995 to 07 Jan 2015, Sydney KSA – Jan 1929 to 07 Jan 2015, Camden Airport – Jan 1943 to 07 Jan 2015.

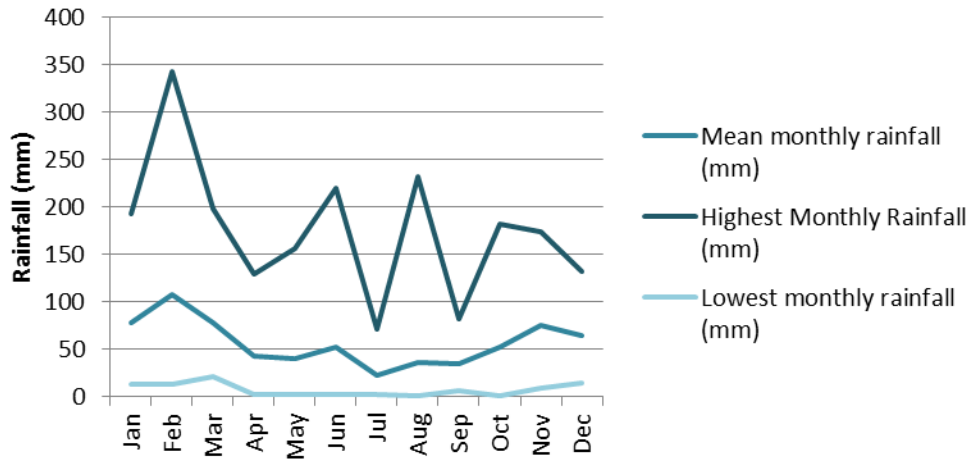


Figure 4.1 Monthly rainfall climatology at Badgerys Creek

The highest monthly rainfall at Badgerys Creek does not follow a smooth annual cycle due to the variable nature of rainfall and also to the short record of observations. However, the average rainfall and lowest rainfall follow a more predictable month-to-month cycle. Monthly rainfall in excess of 50mm on average occurs in the months from October to March at Badgerys Creek.

A statistical rainfall comparison between Badgerys Creek, Sydney KSA and Camden Airport has been supplied in the following sections (4.1.1 to 4.2.3).

4.1.1 Mean monthly rainfall comparison

A comparison of mean monthly rainfall between Badgerys Creek, Sydney KSA, and Camden Airport has been graphed in Figure 4.2.

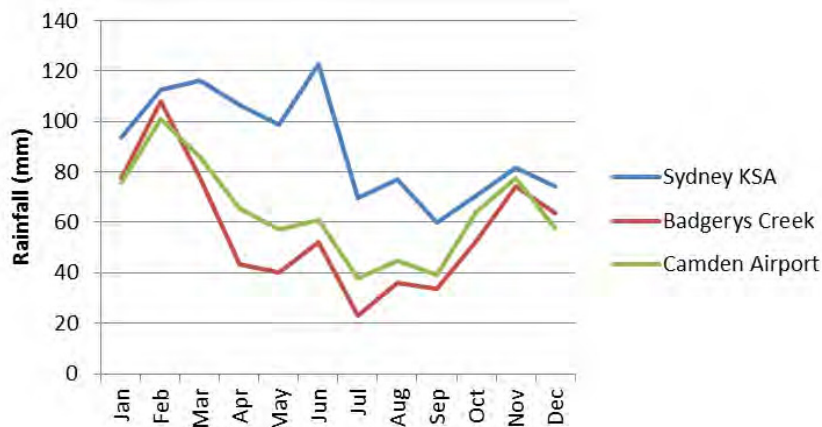


Figure 4.2 Comparison graph of mean monthly rainfall

Badgerys Creek receives slightly less rainfall per month than Camden Airport, and significantly less than Sydney KSA outside of thunderstorm season (October – March). It is possible that rainfall data at the Badgerys Creek site is not representative of climatology given the short period of recorded data.

4.1.2 Highest monthly rainfall comparison

A comparison of highest monthly rainfall between Badgerys Creek, Sydney KSA, and Camden Airport has been graphed in Figure 4.3.

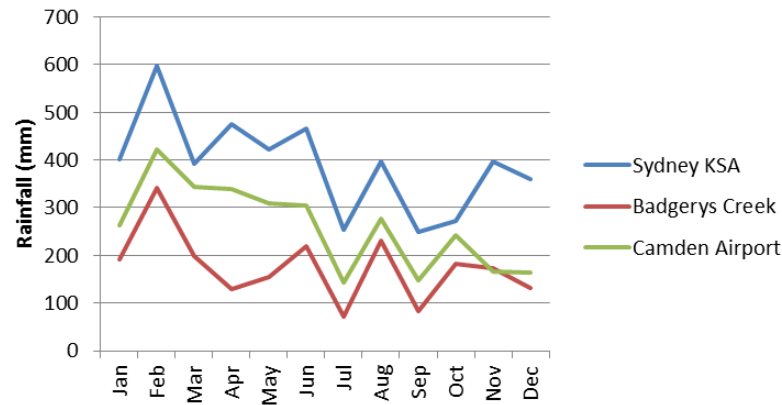


Figure 4.3 Comparison graph of highest monthly rainfall

For each month of the year the highest monthly rainfall on record at Badgerys Creek is approximately half of that ever experienced at Sydney KSA. Moreover, the highest monthly rainfall at Badgerys Creek is consistently lower than at Camden Airport with the exception of November. It is possible that rainfall data at the Badgerys Creek site is not representative of climatology given the short period of recorded data.

4.1.3 Lowest monthly rainfall comparison

A comparison of lowest monthly rainfall between Badgerys Creek, Sydney KSA, and Camden Airport has been graphed in Figure 4.4.

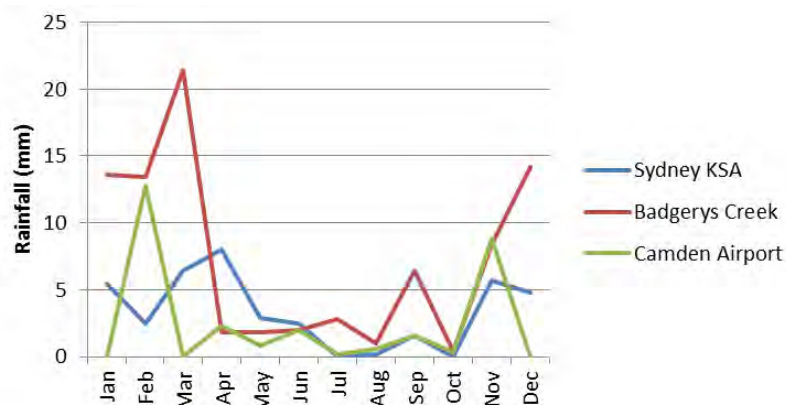


Figure 4.4 Comparison graph of lowest monthly rainfall

On average Badgerys Creek experiences rainfall in every month of the year. More specifically, rainfall records suggest that rainfall is more dependable at Badgerys Creek than at either Camden Airport or Sydney KSA. It is possible that rainfall data at the Badgerys Creek site is not representative of climatology given the short period of recorded data.

4.1.4 Highest daily rainfall comparison

A comparison of highest daily rainfall between Badgerys Creek, Sydney KSA, and Camden Airport has been graphed in Figure 4.5.

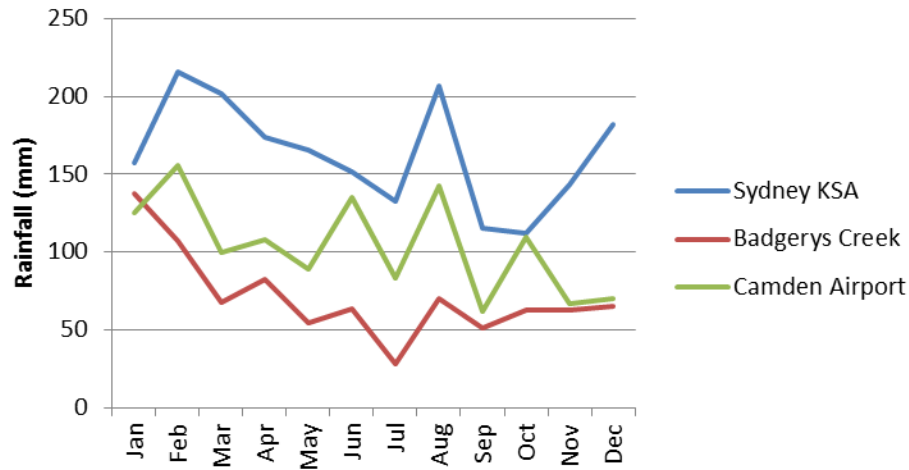


Figure 4.5 Comparison graph of highest daily rainfall

The highest daily rainfall records at Badgerys Creek are lower than those at Sydney KSA and Camden Airport in every month except January at Camden Airport. It is possible that rainfall data at the Badgerys Creek site is not representative of climatology given the short period of recorded data.

4.2 Monthly rain day climatology

Rain day data for Badgerys Creek has been extracted from 4 Dec 1998 to 7 Jan 2015 to produce the statistical summary supplied in Table 4-2.

Table 4-2 Rain day climatology for Badgerys Creek

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Number of Rain Days	11.4	11.3	11.7	10.4	8.2	10.4	7.8	6.7	8.1	8.8	11.4	11.4
Highest Number of Rain Days	18	16	18	18	14	17	15	14	13	17	15	17
Lowest Number of Rain Days	7	6	7	3	3	3	2	2	3	2	6	4

The monthly rain day statistics contained within the Table 4-2 have been graphed in Figure 4.6.

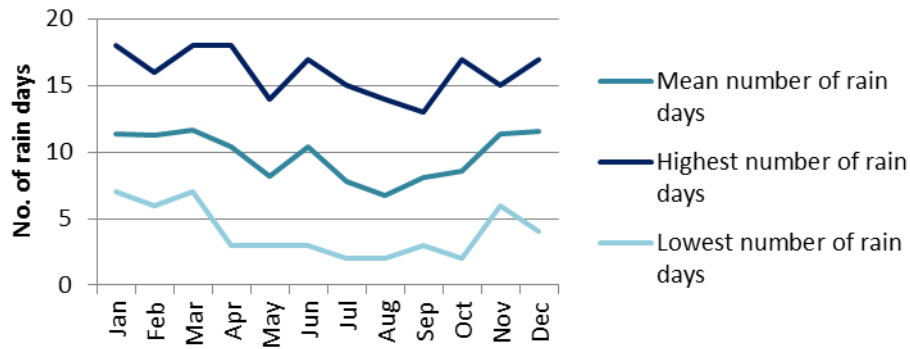


Figure 4.6 Mean monthly rain days at Badgerys Creek

On average, Badgerys Creek experiences rain more than 10 days per month from November to April, and June. There is little variation in the data throughout the year with rain days ranging from approximately 4-16 days per month.

A statistical rain day comparison between Badgerys Creek, Sydney KSA and Camden Airport has been produced.

4.2.1 Mean monthly rain day comparison

A comparison of mean monthly rain days between Badgerys Creek, Sydney KSA and Camden Airport has been graphed in Figure 4.7.

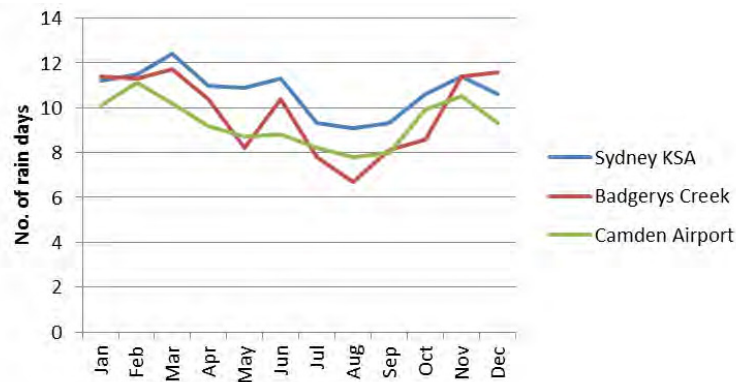


Figure 4.7 Comparison graph of mean monthly rain days

The graph above shows that there is little difference between the mean monthly rain days between the three sites. There is a variation in the data during the winter period with generally slightly lower rain days.

4.2.2 Highest monthly rain day comparison

A comparison of highest monthly rain days between Badgerys Creek, Sydney KSA, and Camden Airport has been graphed in Figure 4.8.



Figure 4.8 Comparison graph of highest monthly rain days

The graph shows that the recorded highest rain days per month are mostly lower at Badgerys Creek than at Sydney KSA or Camden Airport.

4.2.3 Lowest monthly rain day comparison

A comparison of lowest monthly rain days between Badgerys Creek, Sydney KSA, and Camden Airport has been graphed in Figure 4.9.

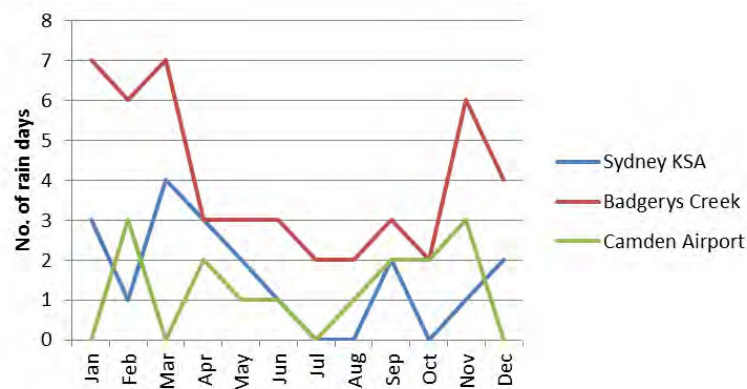


Figure 4.9 Comparison graph of lowest monthly rain days

Although the data appears highly variable, Badgerys Creek experiences higher records of lowest monthly rain days than either Sydney KSA or Camden Airport. The site at Badgerys Creek appears to receive at least 2 rain days per month with an average of 3-4 rain days per month across the year.

4.3 Discussion

Rainfall and the amount of rain days appear to be less variable at Badgerys Creek than at Camden Airport and Sydney KSA. Badgerys Creek experiences lower monthly highs and higher monthly lows in rainfall than the other two airports. This may be due to topographical effects or due to the shorter length of rainfall records.

If the data is representative of climatology then analysis shows that Badgerys Creek experiences less rainfall during recorded rain days than either Camden Airport or Sydney KSA. This theory would align with meteorological concepts and anecdotal evidence from experienced meteorological forecasters.

The construction of an airport is unlikely to have any significant effect on rainfall climatology at Badgerys Creek. Nevertheless the construction of an airport can impact the occurrence of flood effects due to increased runoff. Appropriate control measures and engineering can mitigate surface runoff.

Recommendation 5: Changes in land surface coverage will need to be accounted for in hydrological studies to ensure appropriate control measures and engineering can mitigate surface runoff.

5 Fog and low cloud

Fog is a suspension of water droplets in the air near the surface of the earth. Internationally fog is reported when the horizontal visibility has dropped below 1000 metres (ICAO 2007). However in order to exclude smoke and other circumstances which may cause a reduction in visibility an additional condition of relative humidity above 95% has been applied to data analysis.

For aviation purposes, a visibility of less than 1000 metres must be observed at a height of two metres above the ground or the fog is termed shallow fog. Instrumentation is currently unable to determine the difference between shallow fog and fog at an airport.

5.1 Fog types

There are various ways in which a fog can form in the Sydney Basin. However, fog rarely forms from a single mechanism, usually there are several processes operating collectively.

5.1.1 Radiation fog

Radiation fog, depicted in Figure 5.1, is caused by the rapid cooling of air at the earth's surface. This type of fog generally occurs overnight as heat escapes causing cooler conditions and condensation near the ground. Radiation fog forms in situ and is more prevalent on cloudless nights. This type of fog is common in the western Sydney Basin where surface cooling can occur quickly overnight. Similar atmospheric conditions can occur after rain or thunderstorm events and these events are called post-rain fog events. Additionally radiation fog may be advected by light winds at the surface in the correct atmospheric environment.

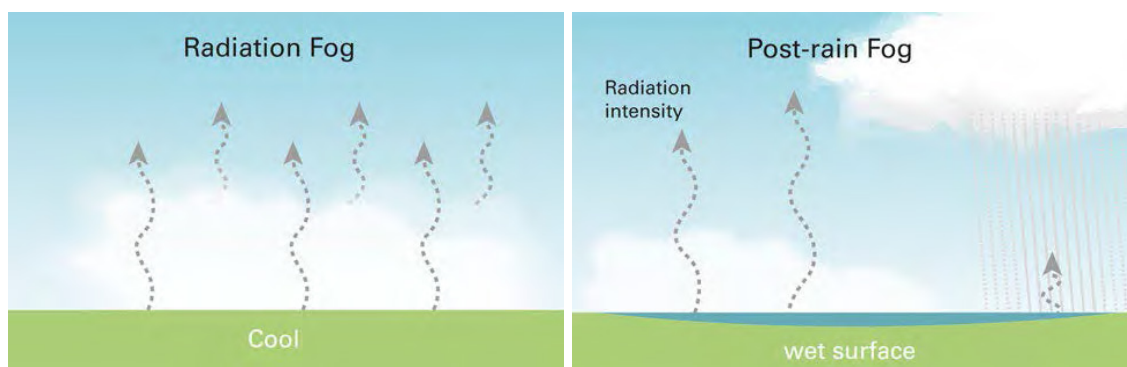


Figure 5.1 Illustration of Radiation Fog and Post Rain Fog Formation Processes (Bureau 2014)

5.1.2 Advection fog

Advection fog develops as warm moist air moves over a cooler surface (Figure 5.2). This type of fog development is not common in the Sydney Basin, however can occur when a warm moist sea breeze propagates inland late into the evening after the western basin has cooled substantially.



Figure 5.2 Illustration of Advection Fog Formation Processes (Bureau 2014)

5.1.3 Valley fog

Valley fog is a type of radiation fog which forms in mountain valleys. This fog can develop on the eastern slopes of the Great Dividing Range and travel into the Sydney Basin with the valley winds overnight.

5.1.4 Sea fog

Sea fog can occur at any time of the year along the Australian Coast. It has the ability to move over parts of the coast and inland, however these events are uncommon and rarely do they propagate extensive distances inland.

5.1.5 Advected fog

Advection fog forms remotely and moves into another space changing and/or displacing the original air mass (Figure 5.3). Advected fog is very common to the Sydney Basin with fog developing in western areas and advecting towards the coast during the evening.



Figure 5.3 Illustration of Advection Fog Formation Processes (Bureau 2014)

5.1.6 Freezing fog

Freezing fog contains a suspension of supercooled liquid water droplets near the earth's surface at temperatures below freezing. Freezing fog is rare in Australia and particularly in the western Sydney Basin but it can occur. Freezing fog has been covered in section 3.6.

5.2 Fog climatology

The AWS at Badgerys Creek currently does not have the capability to determine visibility and cloud. Instead, these parameters have been based on the instrumentation at Camden Airport. Camden Airport is less than 20km to the south of Badgerys Creek and is a similar distance to the east of the Great Dividing Range. Camden Airport has been identified by meteorological forecasters as the most representative site available for fog statistics.

Senior meteorologists experienced in forecasting for the Sydney Basin suggest that fog at Badgerys Creek is likely to occur more often than fog at Camden Airport. However without adequate instrumentation it is impossible to confirm the frequency of fog at Badgerys Creek.

Camden Tower operated by Airservices personnel is active between 2200 – 0800UTC and does not regularly report weather phenomena. It is impossible to verify the occurrence of all operationally significant fog events at Camden Airport without 24hr manual input because the instrument observing visibility reports shallow fog identically to deeper fog events. For the purposes of this section, fog will be said to have occurred when the visibility meter records a horizontal visibility below 1000m as a 10 minute average.

5.2.1 Fog days with visibility below 1000m

Data was available at Camden Airport in 10-minute increments.¹² Approximately 4.5% of the data set did not contain an observation of visibility and cloud due to numerous factors including maintenance and quality control. With a total of 222,488 observations in the data set it was assumed that the missing data was not statistically significant.

The remaining observations were analysed to obtain the number of days in which the visibility dropped below 1000m for a 10-minute period or more for each month. An average was calculated using the four years of data (refer to Figure 5.4), and a fourth order polynomial trend line has been superimposed on to the monthly averages. Associated with the average is a minimum and maximum to indicate the spread of data from year-to-year.

¹² Unless otherwise stated the 10 minute data for Camden Airport was analysed from 26 Aug 2010 to 18 Oct 2014.

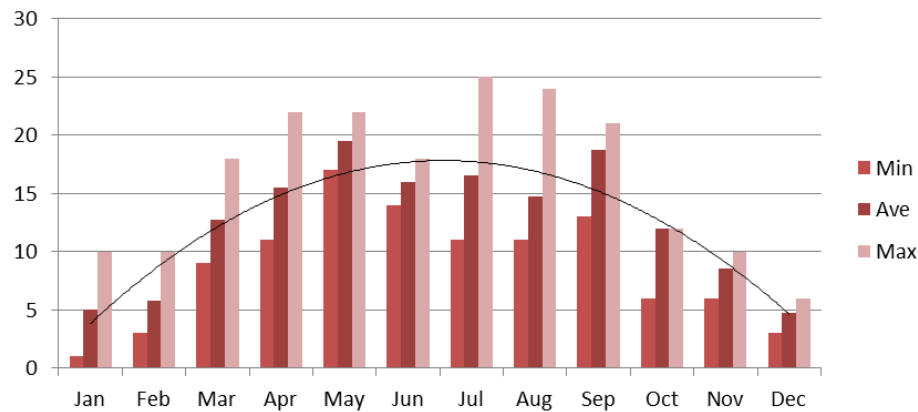


Figure 5.4 Monthly bar graph of number of days with visibility <1000m at Camden Airport

The graph shows that short periods (ten minutes) of low visibility are common during the winter months, and can occur in every month of the year. It was calculated that for the 50 months studied the visibility dropped below 1000m over a 10-minute period at least once on 39% of days. Although short periods of reduced visibility can be of concern, generally they pose no large impact on airport operations.

Further analysis was completed on the data to determine the frequency of fogs that lasted for periods equal to and greater than 1 and 4 hours. These longer periods with visibility continually below 1000m were termed fog 'events'. An average number of fog events per month over the four years of data was examined and has been supplied in Figure 5.5.

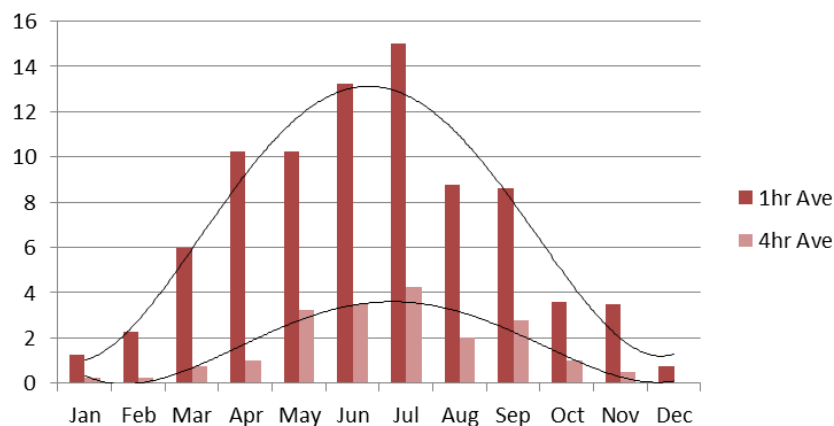


Figure 5.5 Monthly bar graph of number of days with fog events at Camden Airport

The number of events lasting an hour or more occurs on average more than 10 days a month during April to July. The average number of events that lasted more than 4 hours occurs two or more days a month during May to September.

It was calculated that fog events occurring for a period of an hour or more averaged 23% of days per year, whilst in winter the percentage increased to 40%. Furthermore, fog events of periods of four hours or more averaged 5% of days, increasing to 12% of days in winter. The calculated data has been summarised in Table 5-1.

Table 5-1 Summary table of calculated statistics for visibility <1000m

Time period	Daily average
10-minutes	39.4%
≥ 1hr all months	22.7%
≥ 1hr Jun-Aug	40.2%
≥ 4hr all months	5.4%
≥ 4hr Jun-Aug	12.0%

This data has been calculated using the available 50 months of 10-minute data at Camden Airport which may not be representative of climatic trends.

5.2.2 Fog days with visibility below 500m

Most major Australian airports are equipped with Instrument Landing Systems (ILS) which allows a pilot to attempt to approach an airport in reduced visual conditions. However, in the event of a fog it is the Runway Visual Range (RVR) system which becomes critically important. The RVR system may allow aircraft to land in fog provided the RVR is above specified thresholds, the aircraft has the required instrumentation, and the pilot required valid certification.

With the implementation of specific navigational aids it is possible for aircraft to land safely (Autoland) when the RVR visibility is below 600m. Fog events below 500m have been analysed individually for Camden Airport to provide a more comprehensive picture.

The average number of days each month when the visibility dropped below 500m for a period of 10 minutes or more has been provided in Figure 5.6. A fourth order polynomial trend line has been superimposed on to the monthly averages. Associated with the monthly average are minimum and maximum to indicate the spread of data.

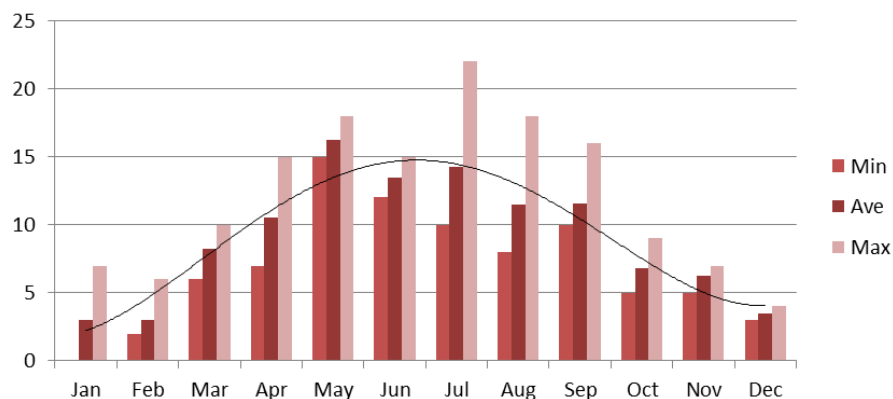


Figure 5.6 Monthly bar graph of number of days with visibility <500m at Camden Airport

The graph illustrates that short ten-minute periods of low visibility are common during the months from May to August. It was calculated that for the 50 months studied the visibility dropped below 500m over a 10-minute period on 30% of the days. Although short periods of reduced visibility can be of concern, generally they pose no large impact on airport operations.

Further analysis was completed on the data to determine the frequency of fogs that lasted for periods equal to and greater than 1 and 4 hours. These longer periods with visibility continually below 500m were termed fog 'events'. An average number of fog events per month over the four years of data was examined and has been supplied in Figure 5.7.

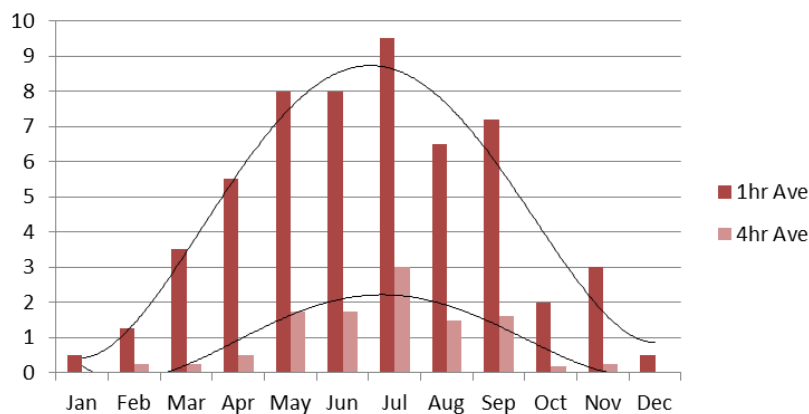


Figure 5.7 Monthly bar graph of number of days with fog events at Camden Airport

The average number of days in which the visibility drops below 500m for an hour or more occurs on more than 5 days a month during April to September. It can be seen that the average number of days in which a fog event has a visibility below 500m for 4 hours or more occurs on more than 1 day a month during May to September. It was calculated that fog events occurring for a period of an hour or more averaged 15% of the days, whilst in winter the percentage increased to 26%. Furthermore fog events with periods of four hours or more averaged 3% of days, increasing to 7% for days in winter. The calculated data has been summarised in Table 5-2.

Table 5-2 Summary table of calculated statistics for visibility <500m

Time period	Daily average
10-minutes	29.7%
≥ 1hr all months	15.2%
≥ 1hr Jun-Aug	26.1%
≥ 4hr all months	3.0%
≥ 4hr Jun-Aug	6.89%

This data has been calculated using the available 50 months of 10-minute data at Camden Airport which may not be representative of climatic trends.

5.2.3 Hourly visibility statistics below 1500m

Whilst 10-minute data is preferred, the four year record at Camden is too short for climatic trends. Additional analysis has been completed on long range 30-minute data to determine the percentage occurrence of visibility conditions below 1500m at each hour of the day for each month of the year. Camden Airport data was extracted from 01 May 1995 to 05 December 2014 (see Table 5-3).

Table 5-3 Table of monthly percentage occurrence of visibility <1500m for each hour of the day at Camden Airport

Time(UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0000	0.0	0.0	0.0	0.0	0.3	1.1	1.1	0.0	0.3	0.0	0.0	0.0
0100	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.0	0.0
0200	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0
0300	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0
0400	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.0
0500	0.0	0.0	0.3	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.3
0600	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.3	0.5	0.0	0.0
0700	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
0800	0.3	0.0	0.0	0.3	0.3	0.8	0.3	0.0	0.0	0.0	0.0	0.0
0900	0.0	0.0	0.0	0.0	0.3	2.8	2.0	0.5	0.3	0.0	0.3	0.0
1000	0.0	0.3	0.0	0.9	1.1	4.0	2.2	0.5	0.0	0.3	0.3	0.3
1100	0.0	0.0	0.0	1.2	2.7	6.2	5.0	1.1	0.3	0.3	0.0	0.0
1200	0.0	0.3	0.0	1.4	3.0	9.4	7.8	3.0	0.3	1.1	0.3	0.0
1300	0.3	0.0	1.3	4.9	8.7	13.4	9.8	5.5	1.1	1.9	0.6	0.3
1400	0.3	1.9	2.2	7.5	12.3	15.3	15.7	7.1	3.9	3.2	1.4	0.9
1500	1.2	0.6	4.6	13.0	16.2	20.0	16.8	10.0	5.6	3.8	3.6	0.9
1600	2.1	2.8	9.4	18.6	20.8	20.3	18.8	12.5	11.9	7.0	5.0	2.9
1700	2.4	3.7	12.9	22.9	23.1	19.0	21.8	14.7	12.5	11.6	8.9	4.4
1800	6.3	5.6	16.7	19.4	20.7	19.9	19.7	14.4	14.5	14.6	11.2	5.5
1900	7.0	7.2	17.3	24.3	19.8	18.4	22.2	14.9	17.5	16.1	10.9	6.7
2000	2.7	5.0	19.9	20.6	18.7	17.2	21.6	15.2	17.3	8.1	4.4	1.4
2100	0.9	1.2	7.0	13.6	18.7	14.7	16.9	14.4	4.9	1.6	0.6	0.6
2200	0.0	0.0	0.5	2.3	4.7	7.2	7.3	3.0	1.1	0.5	0.0	0.0
2300	0.0	0.0	0.0	0.9	0.8	2.9	2.0	1.4	0.0	0.0	0.0	0.0

Periods of visibility <1500m are more frequent during the late evening to early morning in winter months, particularly in May from 2am to 4am LST (1600-1800 UTC) when low visibility conditions are reported on approximately one morning in five. A statistical comparison between Camden Airport, Sydney KSA, Canberra Airport, and RAAF Base Richmond for the months of June and July is shown in Table 5-4.

The analysis included all available data:

- Camden Airport – 01 May 1995 to 05 Dec 2014
- Sydney KSA – 10 Oct 1948 to 05 Dec 2014
- Canberra Airport – 01 Jan 1985 to 05 Dec 2014
- RAAF Base Richmond – 28 Apr 1995 to 27 Jan 2014

The data was tabulated as a percentage occurrence in Table 5-4.

Table 5-4 Comparison table of percentage occurrence of visibility <1500m for each hour of the day in June and July

Time(UTC)	Camden Airport		Sydney KSA		Canberra Airport		RAAF Base Richmond	
	Jun	Jul	Jun	Jul	Jun	Jul	Jun	Jul
0000	1.1	1.1	0.6	0.2	4.4	4.7	1.5	2.3
0100	0.0	0.3	0.3	0.0	2.0	0.7	0.2	0.0
0200	0.3	0.0	0.1	0.0	0.3	0.1	0.0	0.0
0300	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0400	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
0500	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
0600	0.0	0.0	0.2	0.2	0.0	0.1	0.0	0.0
0700	0.3	0.0	0.0	0.0	0.0	0.1	0.4	0.0
0800	0.8	0.3	0.0	0.0	0.0	0.0	0.8	0.2
0900	2.8	2.0	0.0	0.3	0.3	0.1	0.8	0.4
1000	4.0	2.2	0.1	0.0	0.8	0.4	2.3	2.3
1100	6.2	5.0	0.0	0.0	1.4	0.4	3.3	3.2
1200	9.4	7.8	0.1	0.0	2.0	0.4	5.3	4.6
1300	13.4	9.8	0.2	0.0	2.2	0.9	7.5	7.8
1400	15.3	15.7	0.4	0.0	3.7	2.0	12.4	10.1
1500	20.0	16.8	0.6	0.3	6.1	2.7	15.3	13.4
1600	20.3	18.8	0.8	0.4	7.9	5.3	18.5	19.0
1700	19.0	21.8	0.8	0.3	11.1	6.8	20.3	18.5
1800	19.9	19.7	1.6	0.4	13.5	9.8	22.0	23.4
1900	18.4	22.2	1.7	0.6	16.3	11.6	25.0	25.6
2000	17.2	21.6	1.7	0.6	17.3	14.9	25.5	25.6
2100	14.7	16.9	1.9	0.8	17.9	17.4	25.5	21.3
2200	7.2	7.3	2.3	0.9	15.3	15.0	14.5	13.3
2300	2.9	2.0	1.5	0.4	10.8	10.1	7.4	8.9
Mean	7.9	8.1	0.7	0.2	5.6	4.3	8.9	8.3

It can be calculated that conditions which reduce the visibility below 1500m in winter occurs approximately 20 times more often at Camden Airport than at Sydney KSA and approximately 2 times more often than at Canberra Airport. However, RAAF Base Richmond experiences fog of about the same frequency as Camden Airport, or slightly more. Data in Table 5-4 has been displayed graphically for the months of June and July separately in Figure 5.8 and Figure 5.9 respectively.

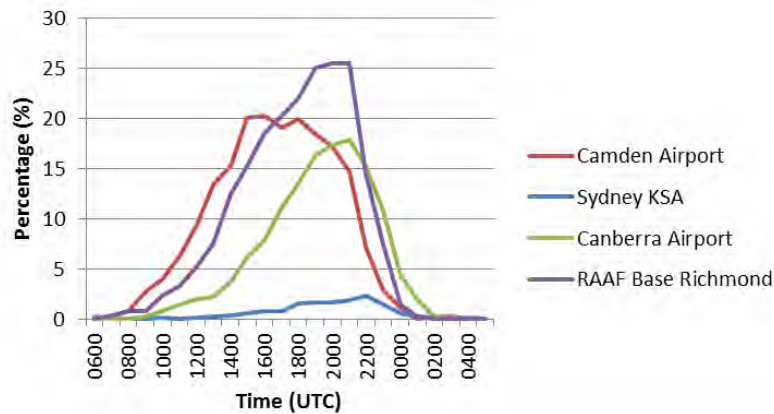


Figure 5.8 Line graph of percentage occurrence of visibility <1500m for each hour of the day in June

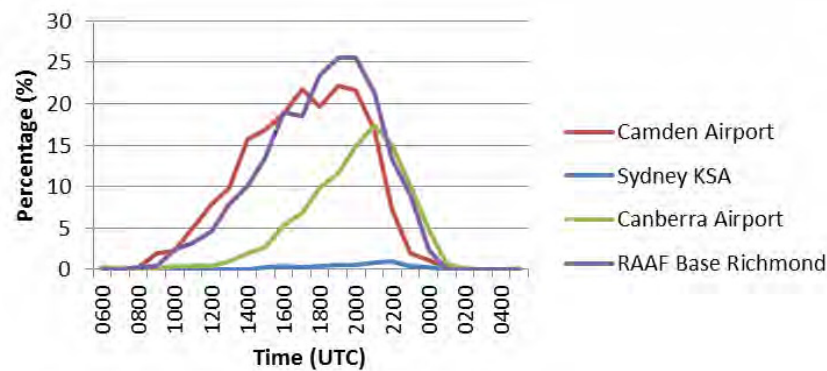


Figure 5.9 Line graph of percentage occurrence of visibility <1500m for each hour of the day in July

The institution of a threshold, such as 15%, assists in the comparison between airports. Camden Airport has at least a 15% chance of visibility below 1500m between the hours of 1400 to 2100UTC in June and July. Similarly RAAF Base Richmond breaches the threshold between 1500 to 2100UTC. Sydney KSA does not reach the 15% threshold at any stage. Canberra Airport has a greater than 15% chance of fog between the hours of 1900 to 2200UTC.

The graphs above show that low visibility conditions at Camden Airport tend to form earlier in the evening and finish earlier in the morning than those at Canberra Airport. Additionally, there is generally a higher probability of having the visibility fall below 1500m for more hours of the night at Camden Airport than at Canberra Airport.

5.2.4 Hourly visibility statistics below 800m

Analysis has been completed on long range 30-minute data to determine the percentage occurrence of visibility conditions below 800m at each hour of the day for each month of the year (see Table 5-5).

Table 5-5 Table of percentage monthly occurrence of visibility <800m for each hour of the day at Camden Airport

Time(UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0000	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0
0100	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0
0200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0400	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0
0500	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3
0600	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0700	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
0800	0.0	0.0	0.0	0.0	0.3	0.6	0.3	0.0	0.0	0.0	0.0	0.0
0900	0.0	0.0	0.0	0.0	0.0	1.7	2.0	0.0	0.0	0.0	0.3	0.0
1000	0.0	0.0	0.0	0.6	0.8	2.8	2.2	0.0	0.0	0.0	0.0	0.0
1100	0.0	0.0	0.0	0.9	1.9	4.8	5.0	0.3	0.3	0.3	0.0	0.0
1200	0.0	0.0	0.0	0.9	3.0	6.0	7.8	2.2	0.3	0.5	0.0	0.0
1300	0.3	0.0	0.8	3.5	6.8	10.8	9.8	4.4	0.8	1.3	0.6	0.3
1400	0.0	0.9	0.3	4.9	9.6	11.4	15.7	4.9	2.2	2.7	1.4	0.3
1500	1.2	0.3	3.2	10.4	10.7	16.6	16.8	7.5	4.5	3.0	2.5	0.9
1600	1.5	2.5	5.9	14.5	17.0	16.0	18.8	9.4	9.0	5.7	3.0	1.7
1700	1.8	3.1	9.9	18.0	19.5	14.9	21.8	11.9	10.5	8.9	6.1	3.2
1800	3.3	4.3	13.2	16.5	16.3	15.6	19.7	12.2	11.1	11.6	8.4	5.0
1900	4.9	5.6	14.9	20.0	15.7	14.7	22.2	13.2	14.7	13.2	8.4	5.6
2000	2.1	4.1	15.3	15.9	14.6	12.6	21.6	11.8	14.4	6.7	3.3	1.2
2100	0.3	0.6	5.6	10.1	14.5	11.0	16.9	11.3	3.7	1.1	0.6	0.6
2200	0.0	0.0	0.5	1.4	3.0	6.0	7.3	3.0	0.9	0.5	0.0	0.0
2300	0.0	0.0	0.0	0.3	0.6	1.7	2.0	0.8	0.0	0	0.0	0.0

Fog occurs more frequently during the late evening to mid-morning in winter months, particularly in July from 3am to 6am LST (1700-2000 UTC) when fog is reported on approximately one in five mornings. Whilst fog is not as prevalent in summer, fog is not uncommon in the early hours of the morning at Camden Airport. A statistical comparison between Camden, Sydney and Canberra Airport for the months of June and July is illustrated in Table 5-6.

Table 5-6 Comparison table of percentage likelihood of visibility <800m for each hour of the day in June and July

	Camden Airport		Sydney Airport		Canberra Airport		RAAF Base Richmond	
Time(UTC)	Jun	Jul	Jun	Jul	Jun	Jul	Jun	Jul
0000	0.3	0.8	0.2	0.2	2.8	2.1	1.1	1.3
0100	0.0	0.3	0.1	0.0	0.5	0.1	0.0	0.0
0200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0700	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0800	0.6	0.3	0.0	0.0	0.0	0.0	0.6	0.2
0900	1.7	2.0	0.0	0.0	0.1	0.1	0.6	0.2
1000	2.8	2.2	0.0	0.0	0.6	0.3	1.5	1.1
1100	4.8	5.0	0.0	0.0	1.3	0.1	2.7	1.7
1200	6.0	7.8	0.1	0.0	1.5	0.1	3.5	3.2
1300	10.8	9.8	0.1	0.0	1.8	0.7	6.9	6.1
1400	11.4	15.7	0.3	0.0	2.6	1.1	10.8	7.8
1500	16.6	16.8	0.4	0.3	3.5	1.6	13.4	10.2
1600	16.0	18.8	0.4	0.3	5.3	3.1	16.3	15.4
1700	14.9	21.8	0.7	0.1	6.9	4.3	18.9	16.4
1800	15.6	19.7	1.4	0.2	10.2	6.5	19.6	20.7
1900	14.7	22.2	1.3	0.5	10.8	7.7	20.4	21.2
2000	12.6	21.6	1.5	0.6	10.3	9.4	22.0	22.1
2100	11.0	16.9	1.7	0.5	11.6	10.4	21.2	17.2
2200	6.0	7.3	1.5	0.7	11.2	9.0	12.2	10.3
2300	1.7	2.0	1.0	0.4	7.0	6.0	5.1	7.5
Mean	6.2	6.5	0.4	0.1	3.6	2.6	7.4	6.8

By considering the 15% threshold it can be seen that Camden Airport has a probability of fog greater than 15% between the hours of 1500 to 1900UTC. RAAF Base Richmond has slightly longer hours of between 1600 to 2100 UTC. Canberra Airport breaches the threshold in June for two hours (2100 to 2200UTC), whilst Sydney KSA probability of fog does not exceed 2%.

From the table, it can be calculated that fog occurs approximately 30 times more often at Camden Airport than at Sydney KSA; and approximately 2 times more often at Camden Airport than at Canberra Airport. Alternatively, fog at RAAF Base Richmond is recorded on average an additional 10% of the time more than at Camden Airport. Data in Table 5-6 has been displayed graphically for the months of June and July separately in Figure 5.10 and Figure 5.11 respectively.

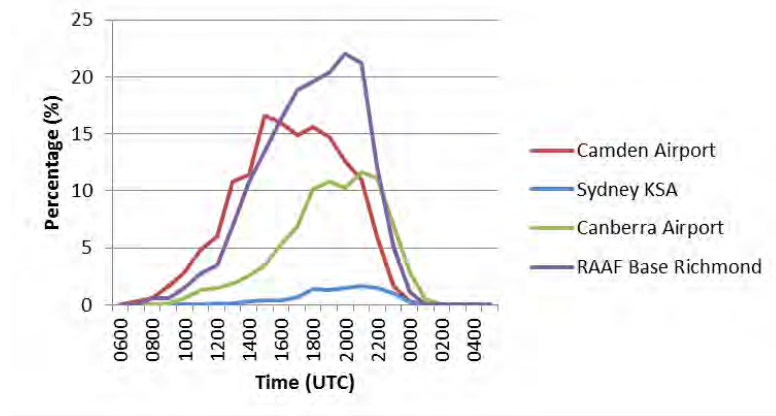


Figure 5.10 Line graph of percentage occurrence of visibility <800m for each hour of the day in June

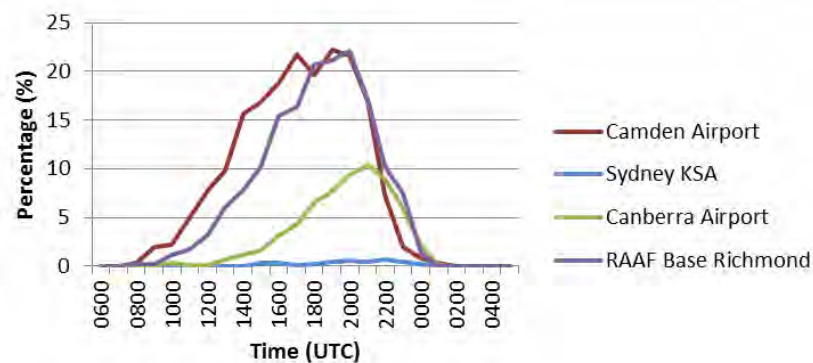


Figure 5.11 Line graph of percentage occurrence of visibility <800m for each hour of the day in July

The graphs above shows that fog at Camden Airport tends to form earlier in the evening and finish earlier in the morning than fog at Canberra Airport. Additionally, it is apparent that there is a higher probability of fog occurring in most hours of the overnight period at Camden Airport than at Canberra Airport.

5.3 Low cloud

The presence of a low cloud ceiling has the ability to affect airport operations and air traffic flow. To ensure that aircrew can adequately prepare for low cloud situations an 'alternate minima' is assigned dependant on aircraft type. The alternate minimum represents the broken cloud height below which additional fuel must be carried to enable the aircraft to safely land at an alternative aerodrome.

Airservices has provided the following preliminary advice regarding the proposed alternate minima for WSA.

Table 5-7 Aircraft category and corresponding alternate cloud minima

Category aircraft	Minima
CAT A/B Alternate	1198ft
CAT C Alternate	1358ft
CAT D Alternate	1488ft

(M. Shepherd 2014, pers. comm., 12 November)

5.3.1 Low cloud at Badgerys Creek

The formation of low cloud is dependent on factors such as temperature, low-level moisture content, low-level wind direction, atmospheric stability, and topography. From data it is possible to calculate the dewpoint depression which is the difference between temperature and dewpoint. Inferred cloud ceiling can be estimated by lifting the air parcel to a point of condensation; however the amount of sky covered with cloud cannot be predicted. For example, a dewpoint depression of 7°C would be equivalent to a cloud base of 2800ft.

A graph of the hourly average dewpoint depression for each month of the year at Badgerys Creek can be seen in Figure 5.12.

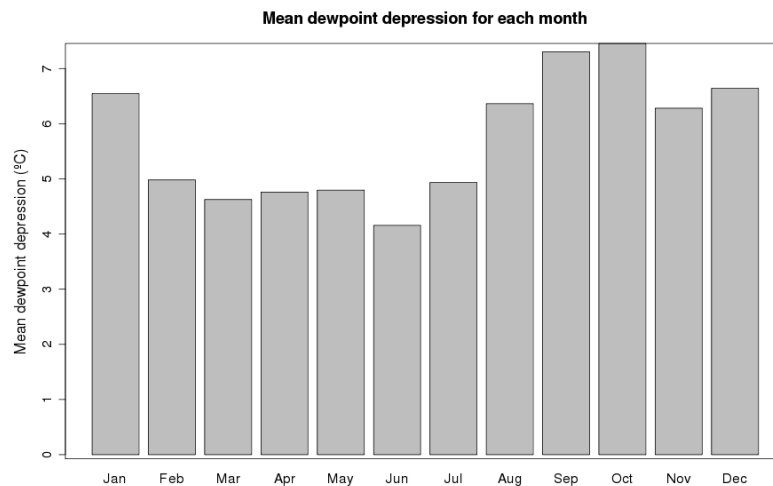


Figure 5.12 Histogram of monthly average dewpoint depression at Badgerys Creek

Given that a dewpoint depression of less than 7 °C would correlate to a cloud base of less than 2800ft, it is possible to infer that a cloud base of 2800ft or below is the mean condition at Badgerys Creek for most of the year. Exceptions occur in September and October when westerly winds and drier conditions prevail over the Western Sydney Basin. An average dewpoint depression can be graphed for every hour of the day, Figure 5.13.

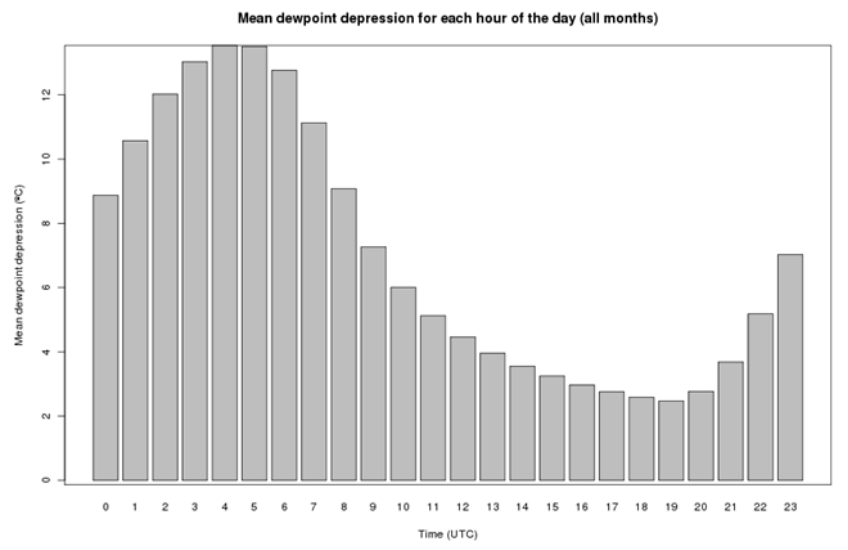


Figure 5.13 Histogram of hourly average dewpoint depression at Badgerys Creek

The histogram shows that higher dewpoint depressions, and therefore inferred cloud bases above 2800ft generally occur between 23-09UTC. On average however cloud bases appear to be below 2800ft for the remainder of the period.

5.3.2 Low cloud at Camden Airport

The AWS at Badgerys Creek currently does not have the capability to determine cloud height or the amount of sky covered. Instead, these parameters have been based on the instrumentation at Camden Airport. This instrumentation has the ability to estimate cloud amount and cloud height. Camden Airport is less than 20km to the south of Badgerys Creek and is a similar distance to the east of the Great Dividing Range. Camden Airport has been identified by meteorological forecasters as the most representative site available for cloud statistics.

30-minute data has been extracted to produce a statistical comparison between Camden Airport, Sydney KSA, Canberra Airport and RAAF Base Richmond for broken low cloud.

Data ranges included the following available data:

- Camden Airport – 01 May 1995 to 05 Dec 2014
- Sydney KSA – 10 Oct 1948 to 05 Dec 2014
- Canberra Airport – 01 Jan 1985 to 05 Dec 2014
- RAAF Base Richmond – 28 Apr 1995 – 27 Jan 2015

The occurrence of broken low cloud below 1500ft has the ability to limit the operations of all categories of aircraft. A graph of the percentage hourly occurrence of broken low cloud below 1500ft is provided in Figure 5.14.

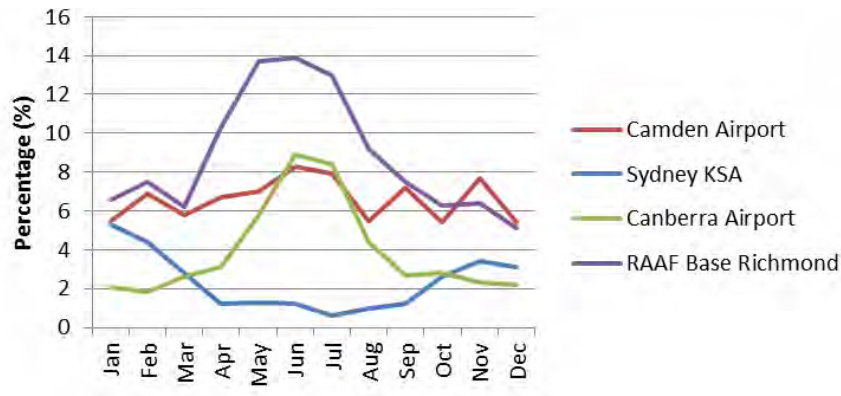


Figure 5.14 Percentage hourly occurrence of cloud base <1500ft

There is little seasonal variation in the development of cloud below 1500ft at Badgerys Creek. Camden Airport and Badgerys Creek are both in close proximity to water sources such as large creeks, rivers, lakes and reservoirs providing rich moisture source all year. It would appear that the availability of moisture combined with surface heating or orographic uplift is sufficient to produce cloud more frequently at Camden Airport than at either Canberra Airport or Sydney KSA.

Broken low cloud below 1500ft occurs approximately twice more at Camden Airport than Canberra Airport for all months except those in winter. However, broken low cloud below 1500ft occurs only half as often at Camden Airport than at RAAF Base Richmond during autumn and winter.

A graph of the percentage hourly occurrence of broken low cloud below 1000ft is provided in Figure 5.15.

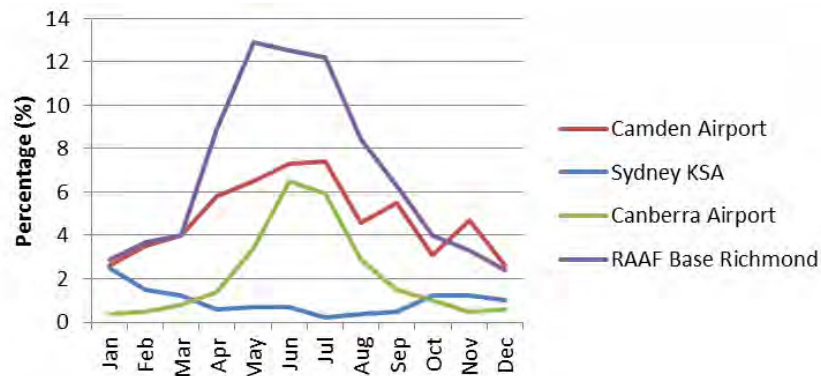


Figure 5.15 Percentage hourly occurrence of cloud base <1000ft

The occurrence of broken low cloud below 1000ft appears to have a more seasonal tendency at Camden Airport. A higher percentage of occurrences of low cloud in winter would not be uncommon and higher levels of radiative cooling overnight would allow for cooler moist conditions at the surface. Broken low cloud below 1000ft would impact air traffic operations at WSA and would cause restrictions on all aircraft categories. Broken low cloud below 1000ft is approximately 5 times more common at Camden Airport than Canberra Airport for all months except those in winter. Again, RAAF Base Richmond experiences broken low cloud below 1000ft approximately twice more often than Camden Airport during autumn and winter.

A graph of the percentage hourly occurrence of broken low cloud below 1000ft is provided in Figure 5.16.

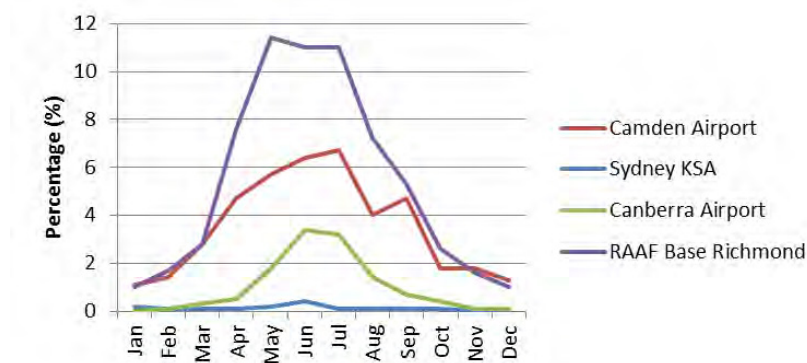


Figure 5.16 Percentage hourly occurrence of cloud base <500ft

The percentage likelihood of broken low cloud below 500ft is approximately three times more at Camden Airport than at Canberra Airport for all months of the year; whereas, RAAF Base Richmond experiences broken low cloud below 500ft almost twice as often during winter.

The percentage occurrence of broken low cloud below 500ft is the highest in winter. The reporting by a ceilometer of cloud below 500ft is often strongly linked to the occurrence of fog.

It is unclear as to the relationship between Camden Airport and Badgerys Creek due to the limited data available at Badgerys Creek. However, it is expected that the occurrence of low cloud at Badgerys Creek would be of a similar order to that experienced at Camden Airport.

5.4 Discussion

The data from Camden Airport suggests that both fog and low cloud could potentially produce low visibility conditions at WSA. More definitive fog and low cloud information would be possible with the implementation of further automatic meteorological equipment at Badgerys Creek.

Recommendation 6: Automatic instrumentation for cloud and visibility should be installed for the collection of climatological information and for the production of forecast products in future

Navigational instrumentation can be installed to mitigate against low visibility phenomena reducing the impact to 24/7 airport operations at WSA.

Recommendation 7: Appropriate low visibility landing equipment, such as runway visual range (RVR) needs to be considered in order to optimise operations at WSA.

The future development of the site into an airport is unlikely to affect low cloud frequency; however an increase in pollutants could potentially affect fog frequency, longevity and severity. The condensation of cloud, including fog, is partially dependent on the availability of Cloud Condensation Nuclei (CCN). CCN are aerosols within the atmosphere with hygroscopic properties which aid in the nucleation of water. Typically a CCN particle will be of the order of $0.1\mu\text{m}$. The combustion of jet fuel releases additional CCN into the atmosphere. The development of a major airport at Badgerys Creek could impact on the fog climatology at the AWS site.

6 Turbulence

Turbulence is the effect caused by a disruption to laminar air flow. Turbulence in the lower atmosphere is generally created by the flow of air around an obstacle such as topography or buildings. However, meteorological conditions such as boundaries between different air masses can also provide turbulent effects.

6.1 Turbulence types

6.1.1 Mechanical turbulence

Mechanical turbulence, as depicted in Figure 6.1, is the mechanical disruption of the ambient wind flow caused by obstructions such as buildings, trees, and rough terrain. These obstacles break down smooth wind flow into complex snarls of eddies.

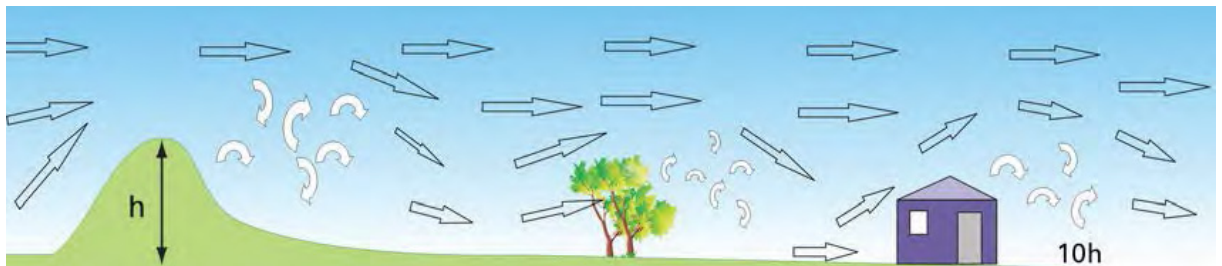


Figure 6.1 Example of effects of obstacle on fluid flow (Bureau, 2014)

An airport can be vulnerable to mechanical turbulence which invariably causes gusty surface winds. Aircraft in a low-level approach or climb can experience air-speed fluctuations and gusts.

The topographical map in Figure 1.2 shows that the AWS site at Badgerys Creek lies approximately 5km to the east at the base of the Great Dividing Range. Assuming the range has an average height of 1.5km it would be expected that mechanical turbulence would affect an area approximately 15km to the east including WSA. Mechanical turbulence in the form of stationary waves will reach Sydney KSA during periods of strong westerly winds and stable atmospheric conditions at ridge height.

Collaborative meteorological forecasting experience indicates that stationary waves typically reach to a height of approximately 5000ft above a mountain ridge. This would equate to approximately 8000ft above the surface at Badgerys Creek.

6.1.2 Rotors

Low level rotors form as friction drags air down the leeward side of a mountain creating a lee wave. The first wave crest has the potential to contribute to rotor formation in some circumstances (refer to Figure 6.2).

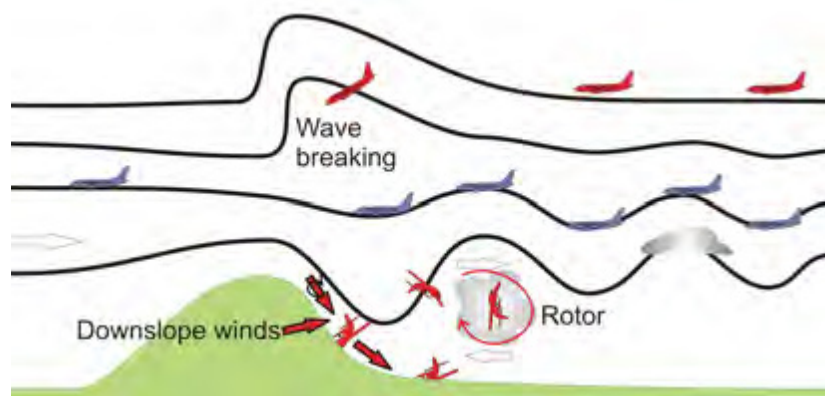


Figure 6.2 Turbulence in lee mountain environment (Bureau, 2014)

It is unclear as to whether the WSA site would be affected by rotor formation however it is a possibility due to the surrounding topography. Anecdotal reports from pilots at Camden Airport suggest that rotors are not likely during prevailing westerly winds at Badgerys Creek as the AWS site is too close to the base of the mountain range. However, pilots believe that sufficiently strong south-westerly winds could produce rotors at Badgerys Creek.

6.1.3 Thermals

Thermals are initiated by strong surface heating of the earth, typically temperature above 35°C. Thermals that produce significant turbulence are generally confined to periods of intense heating in the late afternoon. Thermal turbulence frequently occurs in clear air with no visual signs of the phenomenon. Conditions of light surface winds and strong surface heating are required to produce strong thermal updrafts.

6.1.4 Convective turbulence

Convective turbulence is generated by convective cloud masses such as thunderstorms. Turbulence can range in intensity from light through moderate, to severe or even extreme. The variation in turbulence intensity can be directly related to the strength of updrafts and downdrafts within the clouds, but is not confined to the cloud mass itself. Convective turbulence would frequently occur during the months of November to March when thunderstorm activity is present.

6.1.5 Frontal turbulence

Frontal zones, including southerly changes and sea breeze fronts, may be associated with wind shear and turbulence. Generally the magnitude of wind shear and turbulence associated with these boundaries diminishes as it moves inland. It would be possible to see turbulence associated with a southerly change or sea breeze front at WSA, however it would be highly unlikely.

6.1.6 Wake turbulence

Wake turbulence comprises jet wash and wingtip vortices. Wingtip vortices are produced by the aerofoils on all aircraft, including helicopters, when they are generating lift; they are shed from the wingtips and evolve into counter-rotating circulations that trail behind the aircraft. Jet wash is caused by the air movement through jet engines in the immediate wake of an aircraft departure.

Avoidance of wake turbulence is commonly managed through a system of minimum separation as defined by CASA.

6.1.7 Low-level vertical wind shear

Vertical wind shear is defined as change of horizontal wind direction and/or speed with height as depicted in Figure 6.3.

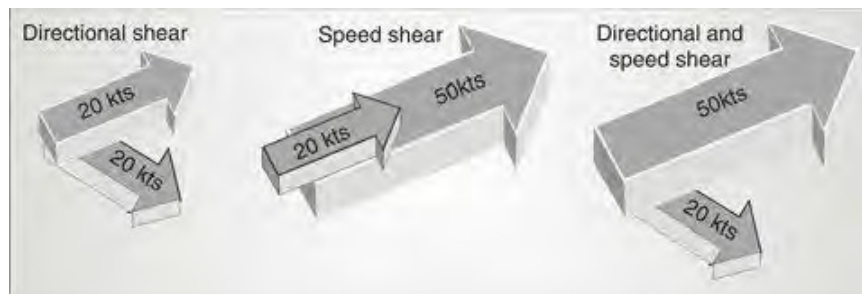


Figure 6.3 Vertical wind shear configurations (Bureau 2014)

Rapid changes in wind velocity encountered during the landing and take-off phases of flight can be extremely dangerous to aircraft (Bureau 2014).

Low-altitude wind shear can affect the aerodynamics of the aircraft in four main ways:

1. Undershooting or overshooting on landing associated with vertical wind shear;
2. Loss of lift on take-off associated with vertical wind shear;
3. Unexpected flight deviations due to horizontal and vertical wind shear generated by convective clouds; and
4. Unexpected rolling and yawing associated with horizontal wind shear.

An aircraft's response to wind shear depends on many factors, including:

- aircraft type, weight, load, speed and phase of flight;
- the scale on which the wind shear operates relative to the size of the aircraft;
- the intensity and duration of the wind shear encounter; and
- pilot intervention (Bureau 2014).

6.2 Numerical modelling of turbulence

The occurrence of turbulence is based on the Bureau's high resolution operational numerical weather prediction models. These models provide the highest resolution, routine depiction of conditions over the Sydney area. The forecast model is acknowledged as one of the leading forecasts systems in the world, and has a very comprehensive depiction of processes that influence the atmosphere. These models are based on the fundamental physical equations of motion for fluid flow (Bureau, 2013).

Linear interpolation of the archived grids from these numerical weather prediction models was used to derive the winds at various levels through the lower troposphere (Bureau, 2013). An algorithm was applied to the wind data to calculate the severity of turbulence and/or wind shear. Inaccuracies in the numerical modelling can be derived from inaccurate topography, incorrect interpolation between grid points, and the inaccurate derivation of the model wind.

Hourly data from the Bureau's numerical weather prediction (NWP) model (Bureau 2013) with a special resolution of 5km has been extracted for the four years including 2011-2014. Data points closest to Sydney KSA, WSA and RAAF Base Richmond (Richmond) have been analysed in the following sections.

6.3 Severe turbulence

Severe turbulence is categorised as producing a vertical wind shear of greater than 20kts in a layer of 1000ft thickness, or due to mechanical turbulence when the wind speed exceeds 25kt perpendicular to the Great Dividing Range. Either circumstance is likely to produce severe turbulence in the vicinity of WSA. Other turbulence types contributing to severe turbulence have not been included at this stage.

The levels included in the study were:

- 10m – 1000ft
- 1000ft – 2000ft
- 2000ft – 3000ft
- 3000ft – 4000ft
- 4000ft – 5000ft
- 5000ft – 6000ft

It is important to note that data pertaining to vertical shear in the bottom 2000ft of the atmosphere has been included in section 6.3 on low-level vertical wind shear. The occurrence of extreme turbulence (vertical shear >40kts/1000ft) will be included in the categorisation of severe turbulence.

Model output has been displayed as both monthly (Figure 6.4), and hourly (Figure 6.5) climatological occurrence rates.

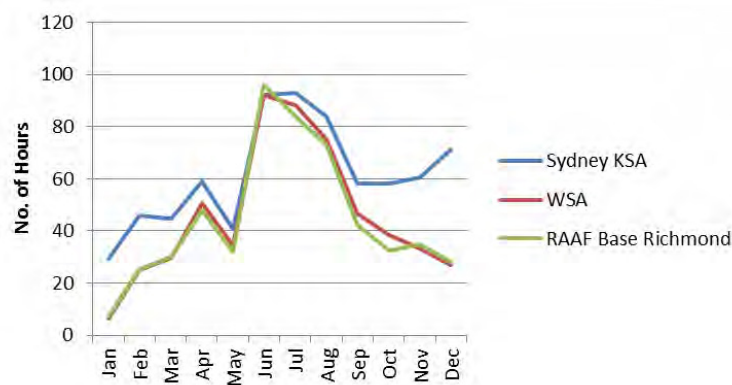


Figure 6.4 Monthly occurrence of severe turbulence

Severe turbulence would be most common in the months of June to August with on average three hours per day expected during these months at Sydney KSA, WSA or Richmond. WSA and Richmond appears to experience slightly less severe turbulence events than Sydney KSA, especially during the months from September to May.

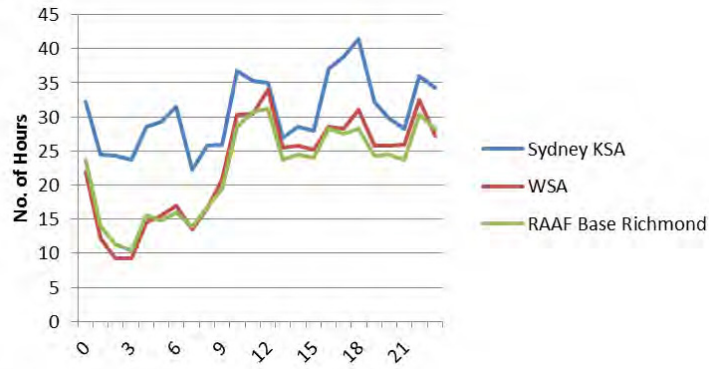


Figure 6.5 Hourly occurrence of severe turbulence

On an hourly basis there are large variations in the expected occurrence times of severe turbulence. Generally severe turbulence would be most likely in the overnight and early morning period at both WSA and Richmond.

6.4 Moderate turbulence

Moderate turbulence is categorised as producing a vertical wind shear of greater than 15kts in a layer of 1000ft thickness, or when the wind speed exceeds 20kt perpendicular to the Great Dividing Range. Model output has been displayed as both monthly (Figure 6.6), and hourly (Figure 6.7) climatological occurrence rates.

It is important to note that cases of severe and extreme turbulence will be included in the categorisation of moderate turbulence.



Figure 6.6 Monthly occurrence of moderate turbulence

The graph above follows an almost identical pattern to the monthly occurrence of severe turbulence. Turbulence of moderate or above severity is most commonly experienced during the months of June to August at Sydney KSA, WSA, and Richmond. During these months there is an average of five hours per day in which conditions of moderate or above severity turbulence is likely to occur. In the months from October to March WSA and Richmond would both be expected to experience slightly less events of turbulence than Sydney KSA.

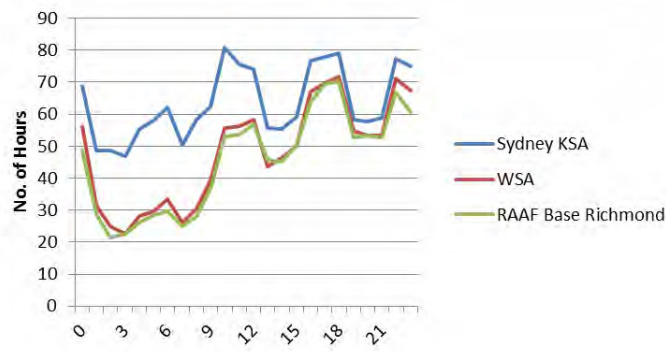


Figure 6.7 Hourly occurrence of moderate turbulence

Figure 6.7 shows similar trend to Figure 6.5. Events of moderate or above severity turbulence are possible during any hour of the day at all three airports. However, there is a slight trend towards less turbulent conditions during the afternoon period at both WSA and Richmond.

6.5 Low-level vertical wind shear

Severe low-level vertical wind shear is categorised as shear of greater than 20kts in a layer of 1000ft thickness in the lowest 2000ft of the atmosphere. The model data was analysed in two layers of wind between 10m to 1000ft, and 1000ft to 2000ft. The data has been displayed as both monthly (Figure 6.8), and hourly (Figure 6.9) climatological occurrence rates.

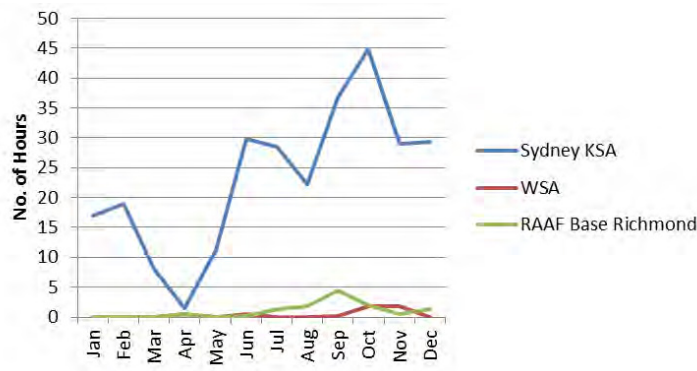


Figure 6.8 Comparison graph of monthly occurrence rates of severe wind shear

There is little to no severe wind shear experienced at either WSA or Richmond in most months of the year. Conversely, severe wind shear is significantly more frequent at Sydney KSA. Severe low-level wind shear most commonly occurs in the months from August to December at Sydney KSA with on average one hour per day.

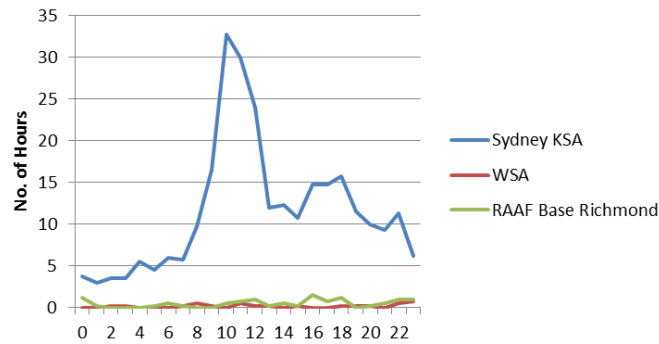


Figure 6.9 Comparison graph of hourly occurrence rates of severe wind shear

The hourly data graphed in Figure 6.9 shows that rare events of severe wind shear at WSA or Richmond could occur at almost any time of the day. In contrast, Sydney KSA would typically experience more severe low-level wind shear events, occurring predominantly during the late evening and overnight period. However, four years of data is not sufficient to establish climatology for wind shear conditions at either WSA or Sydney KSA.

6.6 Discussion

Numerical modelling of both severe and moderate turbulence at WSA shows that there is little additive effect from wind shear to turbulence at any elevation measured. Therefore, the majority of any turbulence experienced at WSA is expected to be mechanical turbulence caused by westerly winds moving over the Great Dividing Range.

It is not possible to determine whether rotors affect WSA but anecdotal observations from pilots operating out of Camden Airport suggests that strong south-westerly winds have the ability to create rotors in close proximity to Badgerys Creek.

At some international airports remote sensing technology called Doppler LIDAR performs an integral part of a low level wind shear alert system. Doppler LIDAR both transmits and received infrared wavelengths to determine the direction and speed of wind in the atmosphere.

Recommendation 8: A Doppler LIDAR system at Badgerys Creek can provide the necessary information for observing wind movement in the lower atmosphere including detection of wind shear and rotors. The Doppler LIDAR system is costly and a cost-benefit analysis would be recommended.

Numerical modelling of winds shows that the expected occurrence of severe and moderate turbulence at WSA is less than that expected at Sydney KSA. It is important to note that model verification consistently shows that forecast winds in the lower atmosphere are weaker than actual winds observed (P. Steinle 2015, per. comm., 7 January). Therefore, the occurrence of turbulence modelled for WSA may be less than actually experienced at WSA.

Additionally, the construction of structures in close proximity to a runway may add to the occurrence of mechanical turbulence events (refer to Recommendation 2).

7 Thunderstorms

Regardless of size or intensity, any thunderstorm is hazardous to aviation. The impacts include disruption to the management of air traffic both enroute and in the terminal area, and disruptions to airport ground operations. Aviation hazards encountered in and near thunderstorms include; severe wind shear and turbulence, severe icing, downbursts, hail, lightning, heavy rain, tornadoes, low cloud, poor visibility, and rapid air pressure fluctuations.

Whilst most 'ordinary' thunderstorms individually have lifetimes of thirty minutes to an hour, under the right atmospheric conditions organised systems of thunderstorms or even individual storms may last for several hours.

7.1 Thunderstorm properties

Within the vicinity of a thunderstorm many additional phenomena other than lightning may occur. Other phenomena can include:

- Tornadoes
- Hail
- Wind Gusts
- Severe Wind Shear
- Severe Turbulence
- Severe Icing
- Heavy Rain
- Low Cloud
- Poor Visibility
- Downbursts and Updrafts
- Rapid Air Pressure Fluctuations

It is important to note that most thunderstorms develop over the Great Dividing Range moving eastwards into the Sydney Basin. The close proximity (approx. 20km) of Badgerys Creek from the mountain ridge would mean that this would only allow for a short lead time for thunderstorm aerodrome warnings at WSA. For example, thunderstorms moving at 20kts towards Badgerys Creek would reach WSA approximately 30mins after initiation.

7.2 Lightning data

Data from February 2008 to October 2014 has been extracted from the Global Positioning and Tracking System (GPATS) for which the Bureau holds a licence agreement. The GPATS system uses a network of sensors that detect the radio frequency signal that is emitted from a lightning strike. GPATS has the ability to record cloud to ground lightning strikes, ground to cloud lightning strikes, as well as cloud to cloud lightning strikes.

7.3 Lightning within 5nm

Thunderstorm cells within 5nm of an airport affect the ability of aircraft to land and taking-off; and the provision of services to aircraft once on the ground. Service disruptions include the ability of aircraft to move into and out of bays, and the absence of ground staff on the tarmac since work health and safety regulations require the removal of ground staff from the tarmac when a thunderstorm is within 5nm.

7.3.1 Monthly climatology

Since February 2008 there have been 500 less lightning strikes in the 5nm surrounding WSA than there have been in the 5nm surrounding Sydney KSA. And, Brisbane Airport has had an approximately 650 more lightning strikes than Sydney KSA within 5nm.

The total number of lightning strikes within 5nm for each month at WSA, Sydney KSA and Brisbane Airport has been graphed in Figure 7.1.

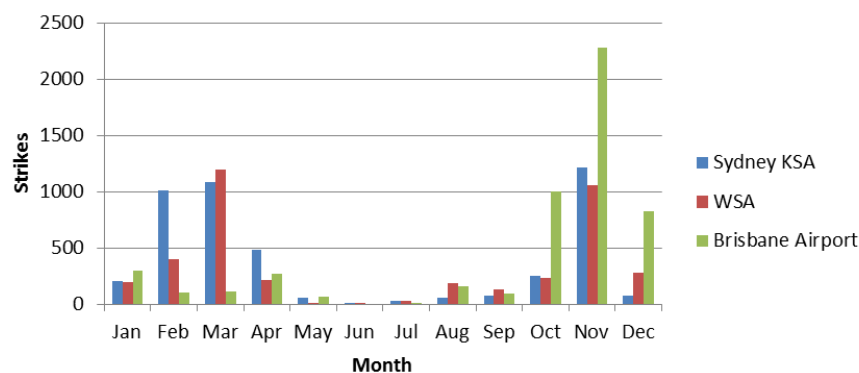


Figure 7.1 Monthly graph of lightning strikes within 5NM of Sydney KSA, WSA and Brisbane Airport

Climatology shows that majority of the lightning within 5nm occur at WSA in the months of November and March. Alternatively, Sydney KSA experiences a high incidence of thunderstorms in February, March and November. Data shows that April can also be very active with respect to lightning at Sydney KSA. Lightning within 5nm of Brisbane Airport occurs most frequently during the months of October to December, and at a higher frequency than at either Sydney KSA or WSA.

Additionally, Figure 7.1 shows that lightning is generally experienced earlier in the thunderstorm season at WSA and becomes less frequent later in the season. This trend confirms anecdotal evidence provided by meteorological forecasters stating that thunderstorm events affecting WSA are most commonly caused by the development of thunderstorms along the Great Dividing Range during summer being steered over the WSA site.

7.3.2 Hourly climatology

The total number of lightning strikes recorded within 5nm of Sydney KSA, WSA and Brisbane Airport for each hour of the day (UTC) has been graphed in Figure 7.2.

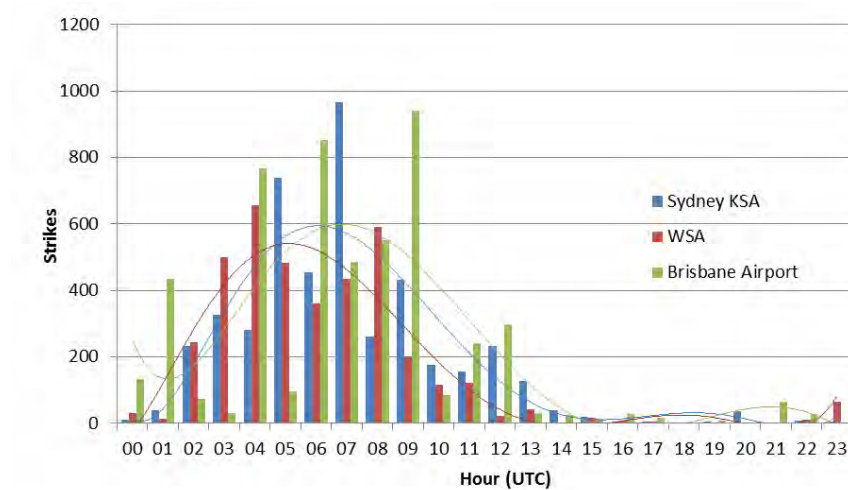


Figure 7.2 Hourly graph of lightning strikes within 5nm of Sydney KSA, WSA and Brisbane Airport

The histogram shows that generally thunderstorms within 5nm are recorded earlier in the day at WSA than at Sydney KSA. Thunderstorms appear to also finish earlier at WSA compared to Sydney KSA. This timing correlates with the typical movement of thunderstorm off the Great Dividing Range over Badgerys Creek and towards coastal areas, including Sydney KSA.

There appears to be fluctuations in the timing of lightning at Brisbane Airport. However, lightning strikes are most frequent during the period from 06 to 09 UTC at Brisbane Airport.

7.3.3 Lightning days within 5nm

The cumulative number of days in which lightning has occurred since February 2008 is provided in Figure 7.3. Calculations for each month have been completed to find an average number of days in which lightning occurred, as well as the maximum number of lightning days for that month.

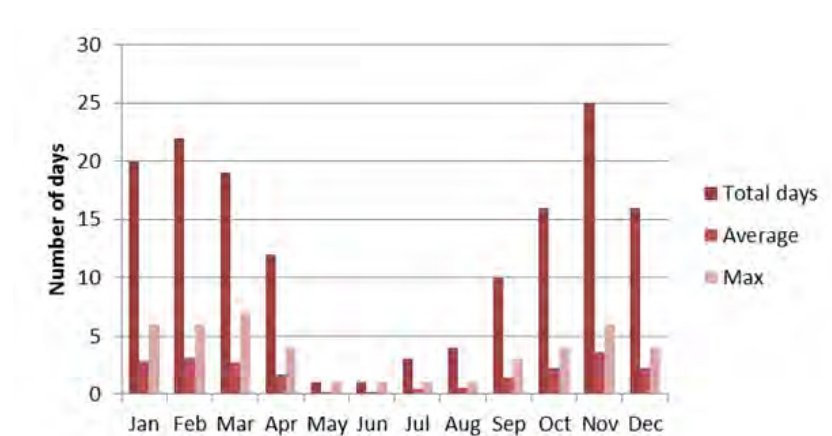


Figure 7.3 Monthly graph of lightning days within 5NM of WSA since Feb 2008

It is expected that lightning within 5nm of WSA will be most active from November to March. The average lightning days per month is less than 4 for each month, however there appears to be some variation between the average and maximum lightning days in the months covering January to March.

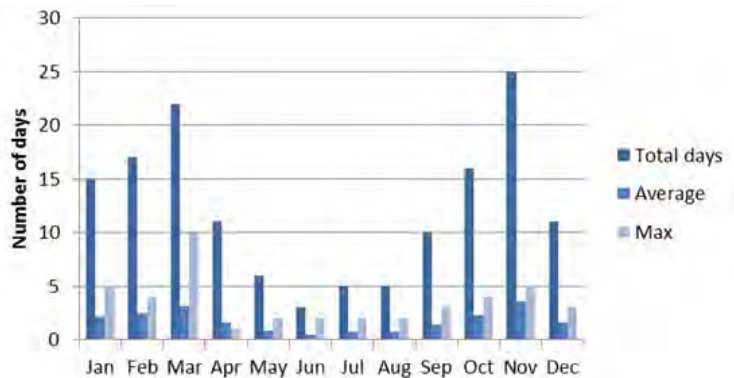


Figure 7.4 Monthly graph of lightning days within 5NM of Sydney KSA since Feb 2008

The months from October to March have been the most active months on average for lightning days at Sydney KSA within 5nm. Like WSA, each month at Sydney KSA records less than 4 lightning days per month, with the most variation in activity occurring in March.

7.4 Lightning within 10nm

It is common for an aircraft to join an Instrument Landing System (ILS) approach is at 10nm. Thunderstorms within 10nm can cause problems for aircraft if they occur on or near the path to final on a runway. Additionally, thunderstorms occurring within 10nm of a major airport place the ground staff in an 'alert' phase for a ramp closure and the potential removal of ground staff from the tarmac.

7.4.1 Monthly climatology

Since February 2008 there have been 1000 less lightning strikes in the 10nm surrounding WSA than there have been in the 10nm surrounding Sydney KSA. Brisbane Airport has experienced another 900 lightning strikes over and above Sydney KSA within 10nm.

The total number of lightning strikes within 10nm for each month at WSA, Sydney KSA and Brisbane Airport has been graphed in Figure 7.5.

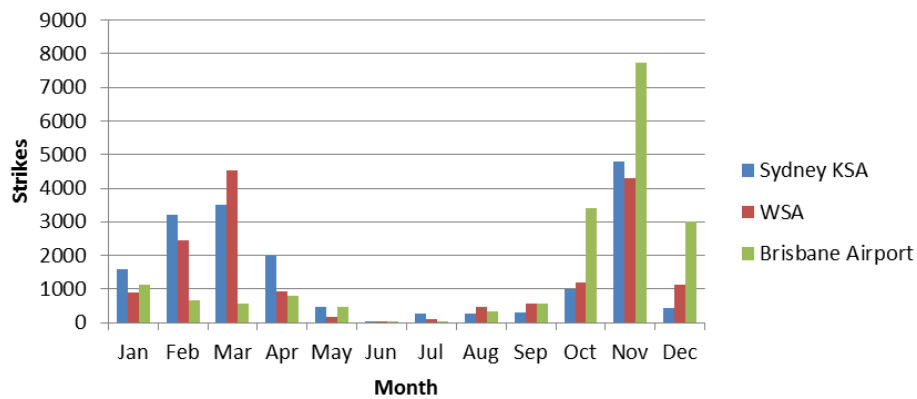


Figure 7.5 Monthly graph of lightning strikes within 10NM of Sydney KSA, WSA and Brisbane Airport

The same seasonal trends can be seen in the 10nm data as was seen at 5nm. The majority of the lightning within 10nm occurred at WSA in the months of November and March, and to a lesser extent February. Alternatively, Sydney KSA experienced a high incidence of thunderstorms in February along with November and March. Brisbane Airport has the most lightning strikes in the months of October to December.

Furthermore, it can be seen that lightning at WSA is more prevalent early in the thunderstorm season but also less frequent later in the season.

7.4.2 Hourly climatology

The total number of lightning strikes recorded within 10nm of Sydney KSA, WSA and Brisbane Airport for each hour of the day (UTC) has been graphed in Figure 7.6.

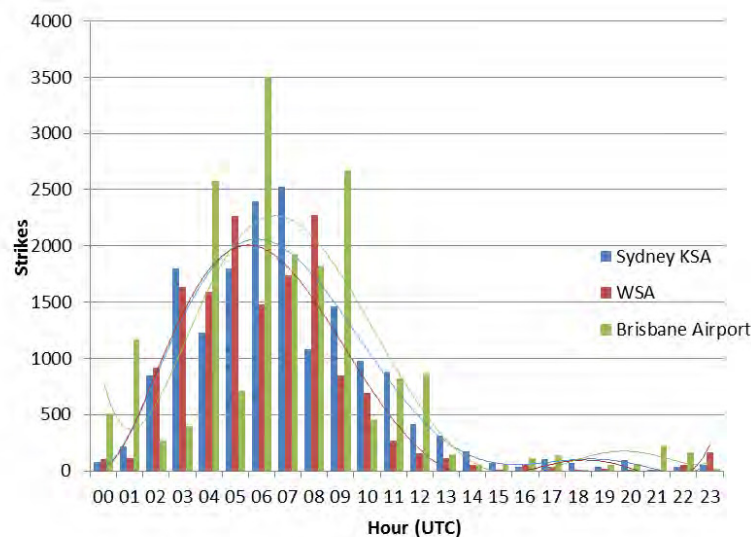


Figure 7.6 Hourly graph of lightning strikes within 10NM of Sydney KSA, WSA and Brisbane Airport

Typically thunderstorms begin to occur at approximately the same time of day at Sydney KSA as they do at WSA within the 10nm radii. Brisbane Airport, however appears to see lightning begin to occur within a 10nm radii a little later in the day than either Sydney KSA or WSA. Thunderstorms appear to typically finish earlier in the day at WSA compared to Sydney KSA; whereas lightning at Brisbane Airport would usually cease later in the day than either of the southern ports.

7.4.3 Lightning days within 10nm

The lightning days have been graphed for both WSA and Sydney KSA to show the total number of days of lightning recorded within 10nm since February 2008, as an average and maximum number of days per month (refer to Figure 7.7 and Figure 7.8).

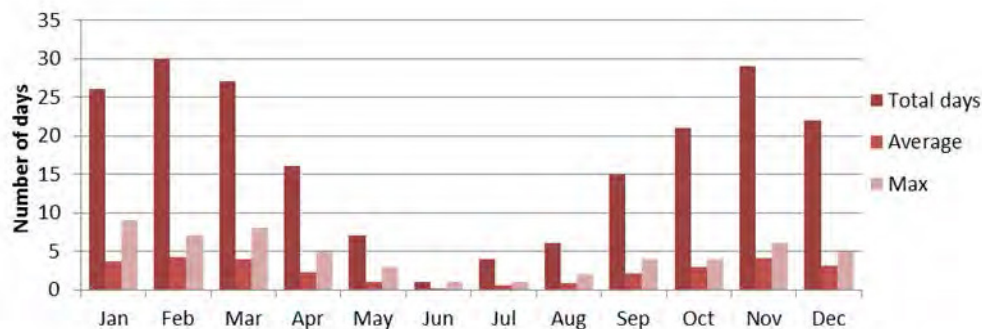


Figure 7.7 Monthly graph of lightning days within 10NM of WSA since Feb 2008

On average the most lightning days within 10nm of WSA would occur in the months from October to March. The average number of days for thunderstorms each month is less than 5, and the variation between the average and maximum lightning days is more pronounced in the first four months of the year.

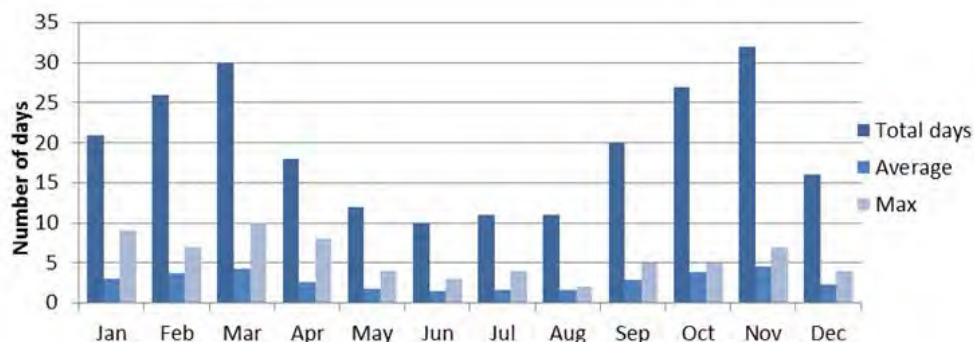


Figure 7.8 Monthly graph of lightning days within 10NM of Sydney KSA since Feb 2008

The data for Sydney KSA is again similar to WSA. The graph shows that the most active months for lightning within 10nm are September to March at Sydney KSA. The average number of days with lightning within 10nm is less than 5, and the variation between the average and maximum lightning days is more pronounced in the first four months of the year.

7.5 Lightning within 45nm

The Terminal Area (TMA) is a 45nm radial area surrounding Sydney KSA. This term is used to describe the designated area of controlled airspace surrounding a major airport where there is a high volume of traffic. The TMA is divided into segments called corridors for arriving and departing aircraft. For Sydney KSA the main airport arrival corridors are to the N and SW.

Thunderstorms within the Terminal Area (45nm) also affect operations. Specifically thunderstorms in the entry corridors to the north and southwest of Sydney KSA can have major impacts on traffic flow.

7.5.1 Monthly climatology

Since February 2008 there have been 2000 less lightning strikes in the 45nm surrounding WSA than there have been in the 45nm surrounding Sydney KSA. Moreover, Brisbane Airport had over 30,000 less lightning strikes within 45nm than either Sydney KSA or WSA.

The total number of lightning strikes within 45nm for each month at Sydney KSA, WSA and Brisbane Airport has been graphed in Figure 7.9.

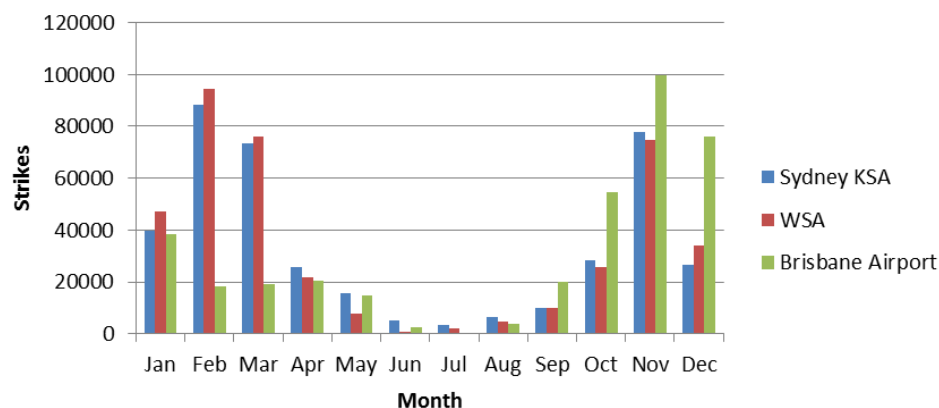


Figure 7.9 Monthly graph of lightning strikes within 45NM of Sydney KSA, WSA and Brisbane Airport

Lightning within 45nm is expected to occur most frequently at both WSA and Sydney KSA from November to March. On the other hand, Brisbane Airport has thunderstorms most frequently in the months from October to January.

7.5.2 Hourly climatology

The total number of lightning strikes recorded within 45nm of Sydney KSA, WSA and Brisbane Airport for each hour of the day (UTC) has been graphed in Figure 7.10.

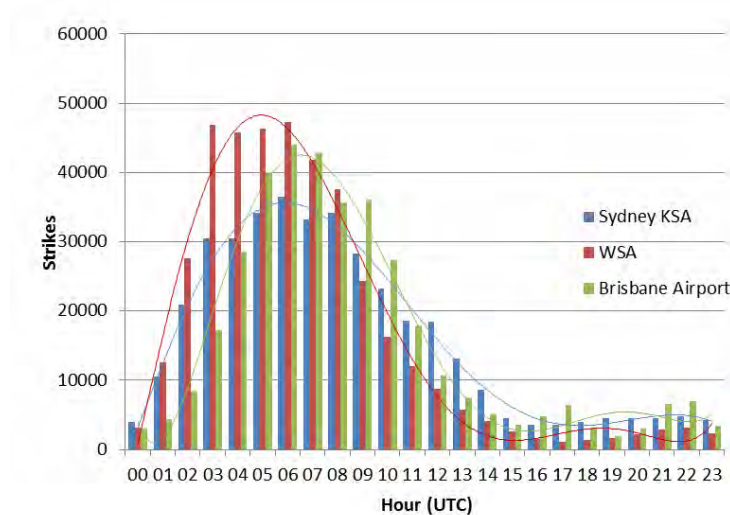


Figure 7.10 Hourly graph of lightning strikes within 45NM of Sydney KSA, WSA and Brisbane Airport

The hourly climatology of lightning strikes within 45nm of WSA shows that whilst the lightning events appear to start and finish later at Sydney KSA, the frequency of the lightning strikes between the hours of 02-08UTC are significantly more at Badgerys Creek than those at Sydney KSA. Brisbane Airport also has a significant peak above the Sydney KSA data between 05-10Z for lightning strikes within 45nm.

7.5.3 Lightning days within 45nm

The number of days in which lightning has occurred since February 2008 has been graphed below in Figure 7.11 and Figure 7.12, as an average and maximum number of days per month.

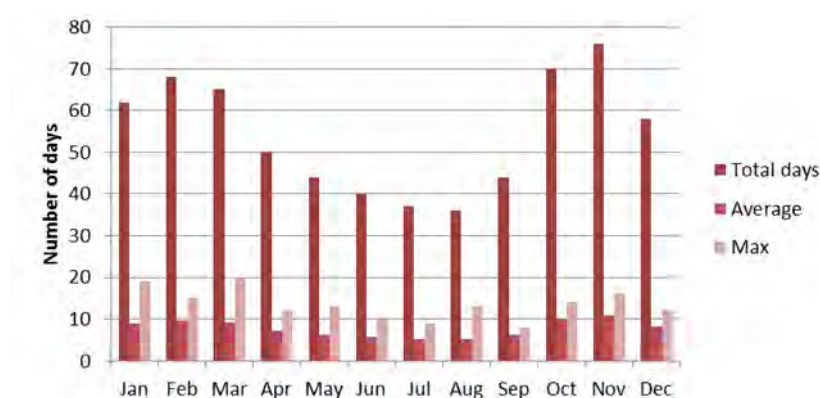


Figure 7.11 Monthly graph of lightning days within 45NM of WSA since Feb 2008

On average the most lightning days within 45nm of WSA are expected to occur in the months from October to March. The average number of days for thunderstorms each month is less than 11, and the variation between the average and maximum number of lightning days is more pronounced in the months of January and March.

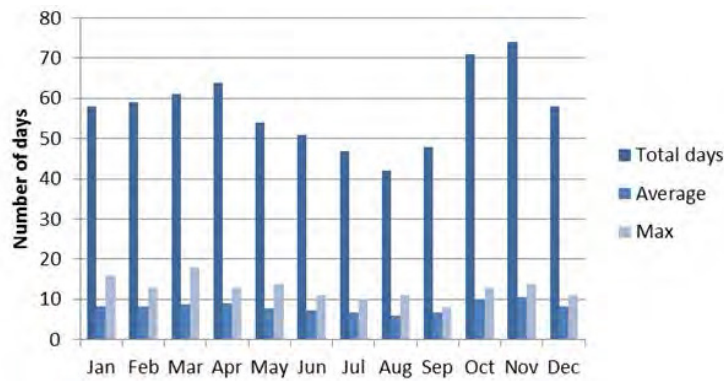


Figure 7.12 Monthly graph of lightning days within 45NM of Sydney KSA since Feb 2008

Thunderstorms within 45nm of Sydney KSA are possible in any month of the year. The average number of days per month in which lightning is recorded within the 45nm radius is less than 11. Variations between the maximum and average number of lightning days appear to be less pronounced with January and March containing the highest data range.

Overall, the expectation of lightning at WSA does not appear to be largely different from that at Sydney KSA; except that there are less total lightning days recorded over the winter months within 45nm of WSA than Sydney KSA.

7.6 Discussion

It is common for thunderstorms to develop on the Great Dividing Range and track over the Sydney Basin during the afternoon. Generally lightning will occur close to WSA earlier in the day and weaken as thunderstorms dissipate after sunset. The airspace within 45nm of WSA would be expected to experience more lightning during the afternoon than Sydney KSA over the same period. It is not possible to determine from the data whether the increase in lightning frequency was due to the occurrence of organised thunderstorms resulting in more lightning strikes, or if there were more thunderstorms in total. However, WSA has experienced fewer lightning strikes in total within 5nm, 10nm, and 45nm than Sydney KSA since February 2008.

The thunderstorm season appears to both start and finish earlier in the year by approximately a month at WSA than Sydney KSA. Outside of the thunderstorm season there are more thunderstorm days at Sydney KSA during the winter months. During data extraction it was observed that the increase in thunderstorm activity over winter chiefly occurred over the ocean to the east of Sydney KSA.

Importantly, it needs to be noted that the close proximity of Badgerys Creek to the Great Dividing Range would only allow for a short lead time for aerodrome warnings at WSA with regards to thunderstorms. Aerodrome warning lead times of less than 1 hour may occur at WSA in future.

For every international airport in Australia the Bureau has a system capable of visually displaying the location of potential thunderstorms with respect to an airport, including size and forecast movement. The Automated Thunderstorm Alert Service (ATSAS) is used in partnership with a procedural alert system for ground based activities at the airport. This system is integral to the safety of both aircraft and ground staff.

Recommendation 9: The Bureau implements an Automated Thunderstorm Alert Service (ATSAS) at WSA to improve the accuracy of thunderstorm forecasting for the airport whilst increasing the operational safety of ground staff and aircraft.

8 Conclusion

The siting of the Western Sydney Airport at Badgerys Creek has many meteorological advantages compared to Sydney KSA, namely the minor exposure to significant crosswind and headwind, the lack of low-level vertical wind shear and lower frequency of thunderstorms.

The runway availability and usability of WSA is primarily determined by crosswind. Mitigation processes and equipment exists for most weather phenomena except for wind at WSA where an intersecting runway to the parallel runway is not planned. The usability of WSA based solely on a prevailing crosswind of less than 20kts is approximately 99.5%.

There are factors which need consideration during the operational planning of the airport that are more likely at WSA than Sydney KSA. These include weather phenomena such as high temperatures, freezing fog and frost. Through adequate planning and infrastructure it is possible to mitigate the influences of most weather phenomena.

The report has revealed that perhaps the most significant aspect of the Badgerys Creek site is likely to be the occurrence of fog. The development of fog overnight in the western Sydney Basin is possible during all months of the year; and often for extended periods of time during winter. It is important to acknowledge that an increase in pollutants in the adjacent atmosphere to the airport could likely affect fog formation in the future. Additional equipment for monitoring visibility and cloud is required in order to develop a true fog climatology at Badgerys Creek, and for meteorologists to improve forecast skill into the future.

Further detailed studies in the following areas may be considered important:

- Correlating low visibility statistics with instrument landing system categories will likely aid airport planners in determining the navigational aids required for optimal usability at WSA.
- Estimated correlation between the occurrence of fog events simultaneously at Sydney KSA and WSA may inform decisions regarding network management.
- Anecdotal evidence of wind rotors at Badgerys Creek indicates that rotors may impact the airport in certain wind regimes. It is unclear as to whether further effort in this area would yield any significant gain in airport usability. A scoping study into different methods of measuring rotors and associated costs could provide key elements for a cost-benefit analysis in this area.
- A comparison study into the numerical modelling of turbulence at major airports such as Brisbane and Melbourne will be considered and conducted as required.
- Research into the potential impact of freezing fog at WSA and associated mitigation measures available for implementation.
- Further calculations for crosswind and headwind will be conducted as required.

9 References

- Bureau of Meteorology (Bureau) 2014, *Aeronautical Forecasters Handbook*, Bureau of Meteorology, Aviation and Defence Weather Services, Melbourne.
- Bureau of Meteorology (Bureau) 2013, *NMOC Operations Bulletin Number 99 – APS1 upgrade of the ACCESS-C Numerical Weather Prediction system*. Retrieved internally 27th January 2015 from <http://web.bom.gov.au/nmoc/stan/opsbull/opsbull99-aps1c-int.pdf>
- Civil Aviation Safety Authority (CASA) 2000, *CASA Media Release - Friday, 24 November 2000: New rules for runway selection*. Retrieved on 9th November 2014 from http://www.casa.gov.au/scripts/nc.dll?WCMS:STANDARD:1001:pc=PC_91736
- International Civil Aviation Organisation (ICAO) 2007, *International Standards and Recommended Practices – Annex 3: Meteorological Service for International Air Navigation (16th Edition)*, ICAO.
- Department of Transport and Regional Development 1999, *Draft EIS Second Sydney Airport Volume 1 Main Report Part C Chapter 9*. Retrieved 9th November 2014 from http://www.blacktown.nsw.gov.au/Planning_and_Development/Strategic_Planning/Sydneys_Second_Airport_Draft_EIS_from_1997