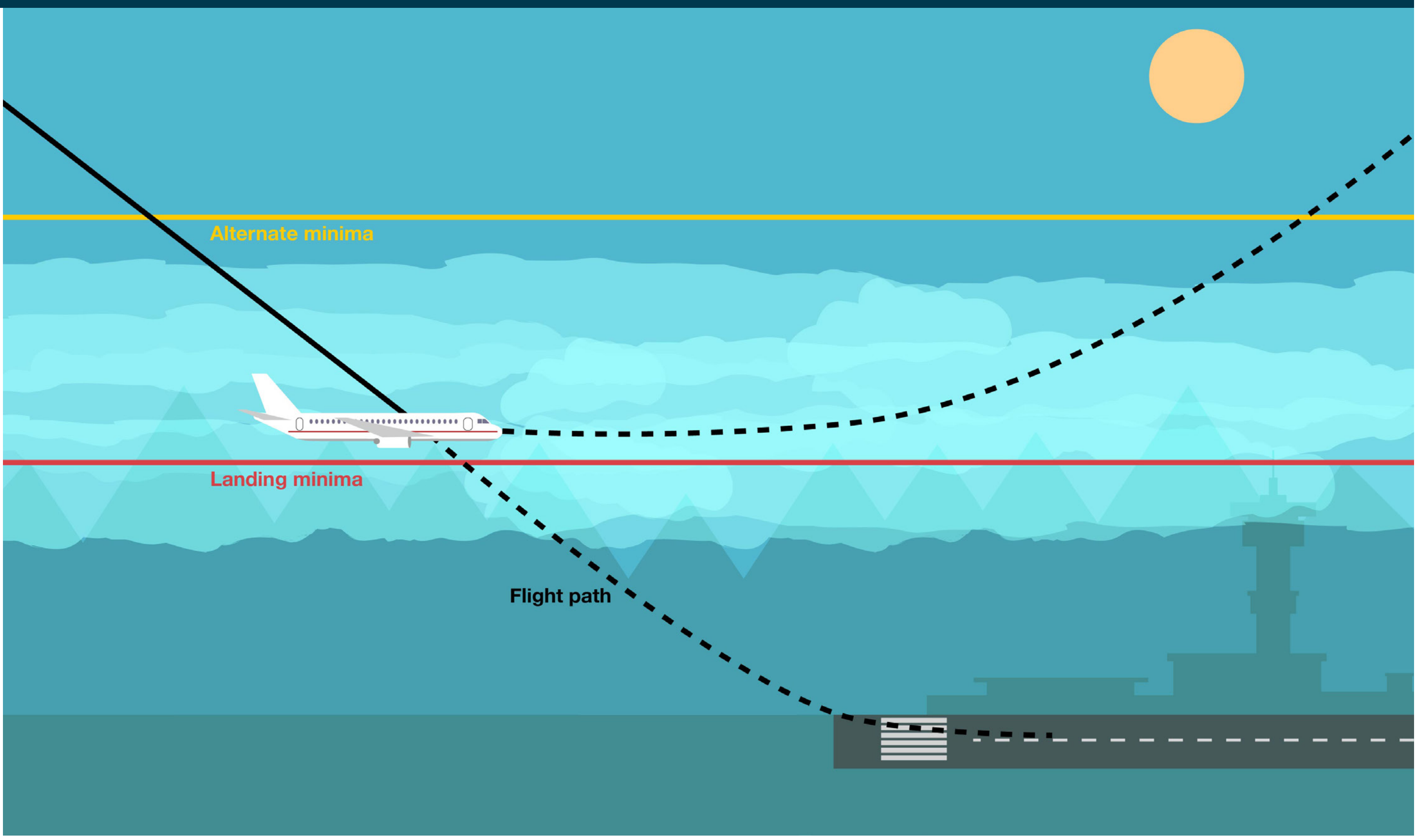
Australian Government

Australian Transport Safety Bureau

The effect of Australian aviation weather forecasts on aircraft operations:

Adelaide and Mildura Airports, Australia



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Addendum

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Safety summary

Why did the ATSB do this research

A number of unforecast weather episodes relating to flights into major Australian airports have led to unforeseen diversions, holding, and in some cases, landing below published safe limits. For example, on 18 June 2013, two flights encountered unforecast weather en route to Adelaide, South Australia, leading to a diversion to Mildura Airport, Victoria. Upon arrival, both encountered weather unsuitable for landing.

Aerodrome weather forecasts allow pilots and operators to develop a contingency plan during flight planning and en route (such as carrying additional fuel for holding or diversion) when there are indications of conditions potentially unsuitable for landing at the intended destination. Weather unsuitable for landing mostly involves thunderstorms, a low cloud base and/or low visibility, and to a lesser extent, strong winds.

This is the first report in a series covering Australian airports supporting regular passenger transport operations. The results will assist aircraft operators to focus on the highest risk seasons and times of day for weather reliability, facilitating better flight planning and support for pilots. They will also allow for more informed prioritisation of investment decisions about aircraft and aerodrome navigational equipment. This report focuses on Adelaide and Mildura Airports.

What the ATSB found

Weather conditions were reported as unsuitable for landing in about one in every 22 days at Adelaide Airport and one in 10 days at Mildura Airport. Considering the total time, episodes of weather below the landing minima were rare, accounting for only 0.23 per cent of the time at Adelaide and 0.99 per cent at Mildura.

It was very rare for forecasts not to provide sufficient indication of conditions unsuitable for landing (less than 0.1 per cent of all time). However, when weather conditions were unsuitable for landing, aerodrome forecasts (TAFs) did not provide sufficient indication of these conditions 13 per cent (Adelaide) and 9 per cent (Mildura) of that time. At Adelaide, using the shorter-term trend forecasts (TTF) alone, unsuitable conditions were not indicated 22 per cent of that time.

Taking into account aircraft traffic arrival patterns, an average of 15 (Adelaide) and four (Mildura) aircraft were expected to arrive during unforecast weather each year by these TAFs. For TTFs used alone at Adelaide, 27 aircraft were expected to be affected per year. Mornings had the most aircraft arrivals affected by unforecast weather, especially in June (Adelaide) or July (Mildura).

The potential impact on safety, measured by unexpected holding time required if a flight crew was unable to land due to unforecast weather varied considerably. Unexpected holding periods of 30 minutes or more were calculated in Adelaide mornings 53 per cent of the time when unsuitable conditions were not indicated by the TTF. For TAFs, this was 36 per cent of the time for Adelaide mornings, and 64 per cent of the time for Mildura mornings.

Retrieving the TAF closer to the intended landing time led to a lower incidence of insufficient indications of weather conditions that were unsuitable for landing, particular in the mornings. At Adelaide in the mornings, an increase of 2.3 aircraft arrivals per year were predicted during unexpected unsuitable conditions for every additional hour prior to arrival that a TAF is retrieved.

Safety message

In the morning at Adelaide and Mildura, it is relatively more important that forecasts are retrieved at the latest possible time (before the point where a diversion is no longer possible) prior to arrival. Using the alternate minima rather than landing minima for all decision making, both for pre-flight planning and in-flight, considerably improves the chances of not being exposed to unexpected unsuitable conditions for landing.

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Executive Summary

Context

Over the past 15 years, a number of unforecast weather episodes relating to flights into major Australian airports have led to unforeseen diversions, holding, and in some cases, landing below published safe limits.[1] This research investigation was initiated due to these occurrences, and because of the limited amount of Australian-based research in this area. The objective of this research was to understand how the reliability of weather forecasts affects the ability of flight crew to conduct safe landings at Australian airports.

One occurrence, on 18 June 2013, involved two Boeing 737-800 aircraft that encountered unforecast weather en route to Adelaide, South Australia, leading to a diversion to Mildura Airport, Victoria. Upon arrival, both aircraft encountered weather unsuitable for landing. Both aircraft landed in conditions below the published safe limits, with one aircraft also landing in a fuel critical state (ATSB occurrence investigation AO-2013-100).

Due to the involvement of Adelaide and Mildura Airports in the above occurrence, the current research report covers the operational reliability of weather forecasting of Adelaide and Mildura Airports. This is the first report in a planned series covering Australian airports supporting regular public transport operations.

A further objective of this research was to understand how weather forecasting can affect safe landings by aircraft engaged in air transport operations. To achieve these objectives, an analysis was conducted comparing all aviation weather forecasts and coinciding reported weather observations.

Background

Limits on safe landings

Where there is less than visual meteorological conditions[2] (VMC) at an airport, the ability of pilots to land their aircraft can be affected. The ability to land below VMC (instrument meteorological conditions (IMC)) can be influenced by:

- aircraft and aerodrome navigational equipment (including aircraft navigational instrumentation and aerodrome radio navigational aids)
- published instrument approach procedures
- aircraft performance limitations.

The combination of these parameters are used to define if an aircraft is able to land given certain weather conditions.

Aircraft and aerodrome navigational equipment

To land in conditions of reduced visibility or low cloud, a combination of aircraft and aerodrome navigational equipment can be used to guide an aircraft toward and in-line with a runway without the pilots obtaining visual reference to the ground. The more precise and reliable the equipment, the lower and closer to the runway an aircraft can fly.

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[1] ATSB investigations of incidents related to unforecast weather include: 199904029, 200401270, 200605473, AO-2012-073, AO-2015-067, and AO-2013-100, available on the ATSB's website at www.atsb.gov.au.

[2] Visual Meteorological Conditions is an aviation flight category in which visual flight rules (VFR) flight is permitted—that is, conditions in which pilots have sufficient visibility to fly the aircraft maintaining visual separation from terrain and other aircraft.

The typical process of landing in adverse conditions involves an approach to a runway being flown without the pilots being able to see the runway. Descent continues solely using flight instruments until descending to a minimum allowable point. At that point, the landing will be aborted unless visual contact is established with the intended landing runway, where the approach to landing would be continued.

Published instrument approach procedures

Instrument approach procedures (IAPs) are produced for many Australian airports and describe pre-determined flight paths using selected navigational equipment. Each IAP is generally limited to an approach toward a particular runway using one or more aircraft instruments paired with corresponding aerodrome navigational aids or satellite navigation systems.

These published instrument approaches include two pertinent parameters:

- the minimum height above the ground[3] that a flight crew can safety descend to prior to being required to abort the landing if they cannot see the runway
- the minimum visibility.

The minimum allowable height and minimum visibility are referred to as landing minima criteria.

Aircraft performance limitations

Modern aircraft are designed to be very resilient against severe weather conditions during landing, with relatively high strength and controllability allowing landing in adverse conditions within safe limits. However, established limits exist that are designed to ensure safe margins are maintained.

In terms of an aircraft conducting a landing, three main parameters were considered in addition to those mentioned above:

- maximum demonstrated crosswind
- maximum tailwind
- thunderstorms.

Meteorological observation reports

The Australian Bureau of Meteorology (BoM) produce many specific products for the aviation industry, including aerodrome weather reports, referred to as METARs (routine reports) and SPECIs (special reports). These may be used by flight crews to provide an indication of the observed weather conditions in the immediate past.

METARs provide a representation of *observed conditions* near the time of release. Whenever conditions are below minima criteria or have recently improved, a SPECI is produced in lieu. These are generally released on a more frequent basis, and as such can be expected to provide a more accurate representation of observed conditions compared to METARs.

If weather conditions deteriorate below established limits for a safe landing, they are said to be *below the landing minima*. Conditions are considered to be below the landing minima when any of the following are observed at an aerodrome:

- low visibility
- low (cloud) ceiling[4]
- above aircraft maximum demonstrated crosswind
- above aircraft maximum tailwind
- presence of thunderstorms.

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3 Referred to as either a decision altitude or minimum descent altitude depending on the type of approach.

4 The ceiling is the height above the ground that more than half of the sky is covered by cloud when observed from the ground.

METAR and SPECI reports contain information to assess each of these criteria, which can be used by flight crew (and in this analysis) to indicate the suitability of conditions for landing.

Planning for safe landing using forecasts

A number of different types of aviation weather forecasts exist to help inform decisions. These may be retrieved prior to flight for the purposes of flight planning for arrival at the planned destination at a particular time, or the planned passage through an area. Additionally, forecasts may be retrieved in-flight to check whether new forecasts predict different conditions to those originally anticipated.

Two of these weather forecasts are aerodrome forecasts (TAFs) and trend forecasts (TTFs) which focus on weather up to 9 km (5 NM) from an airport. An important function of TAFs and TTFs is their use for assessing if a contingency plan is required. That is, a plan to ensure safe landing if poor weather eventuates at the intended destination at the intended time of arrival. These typically involve a plan to hold until the weather improves or a diversion to an alternate airport, and therefore normally require additional fuel to be carried.

TTFs are short term forecasts only available for major airports, including Adelaide, but not Mildura. In Australia, these are valid for 3 hours from the time of release, while in other parts of the world, are typically available for 2 hours.

The type of routine TAFs vary based on the size of an airport:

- Adelaide is a category A (international) airport. TAFs are released every 6 hours, and are valid for 24 or 30 hours.
- Mildura is a category B (large) airport. TAFs are released every 6 hours, and are valid for 12 or 18 hours.

TAFs and TTFs are the only forecasts that are allowed to be used for the planning of a flight to conduct a safe landing at destinations with prescribed instrument approach procedures.[5]

Key terminology used in this report

The analyses of data presented below refers to various states described above through the use of *unprimed* and *primed* as follows:

- *Unprimed observation below the landing minima* (*unprimed observation)*. This is the unsafe situation where landing is not possible at the time of arrival (below the landing minima) but there was no contingency plan required from the forecast as it predicted conditions above the alternate minima.
- *Primed observation below the landing minima*: Although landing is not possible at the time of arrival (below the landing minima), a contingency plan was required from the forecast as it predicted conditions below the alternate minima.
- *False alarm*: The forecast did require a contingency plan, however, no degraded weather conditions (below the alternate minima) were observed at the time of arrival. There are no safety implications with false alarms, although there can be commercial implications.

Methodology

For Adelaide and Mildura, every forecast and observation issued between 2009 and 2013 was provided by the Australian Bureau of Meteorology (BoM). Aircraft arrivals data were provided for each hour between 2010 and 2013 by Airservices Australia, and was used as the basis for modelling expected aircraft arrivals.

5 Aeronautical Information Publication ENR 1.1 59 – 18 August 2016.

The analysis focussed on identifying forecasts that did not provide sufficient indication to flight crews and other operational personnel when reported conditions were unsuitable for an aircraft to land. An aircraft arrivals model was then used to estimate the number of aircraft expected to arrive during these times.

Adelaide and Mildura comparisons

Table 1 presents the overall results, detailed in the sections below, as a comparison between the TAF and TTF analyses at Adelaide Airport and TAF analyses at Mildura Airport. To provide further context, analyses for conditions below the landing minima are also shown pictorially for observations in Figure 1, and expected aircraft arrivals in Figure 2.

Table 1: Summary of overall results, simulations averaged for retrieval 0 to 2 hours prior to arrival, Adelaide and Mildura Airports 2009 to 2013

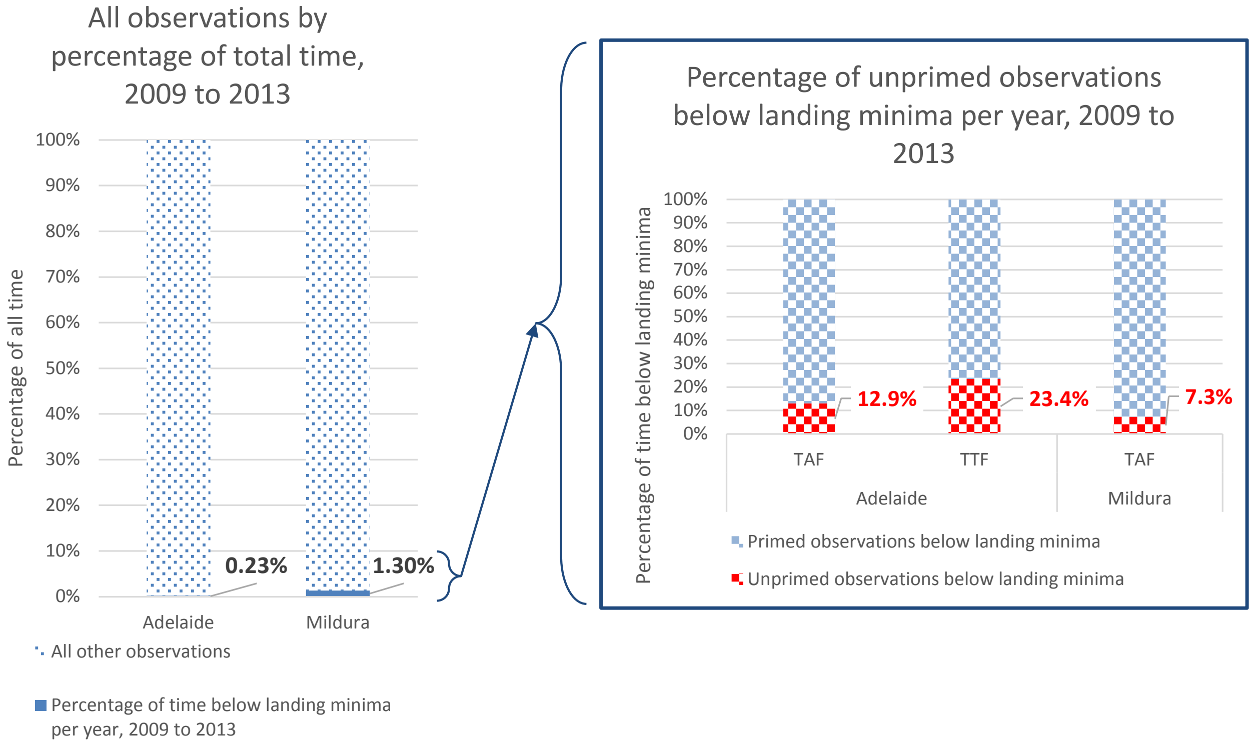
		Adelaide Airport		Mildura Airport
		TAF	TTF	TAF
Time				
	Observations below landing minima (hours per year)	20.1	20.1	114.2
	Unprimed observations (hours per year)	2.6	4.7	8.3
	False alarms – (percentage of all time)	6.58%	4.96%	13.25%
Aircraft arrivals (per year)				
	Expected arrivals during observations below landing minima	115	115	51
	Expected unprimed aircraft arrivals	15	27	3.6
	Expected aircraft arrivals with false alarms	3,160	2,387	612
	Total arrivals per year	51,241	51,241	4,849

On average, the likelihood of unsuitable conditions for landing was rare for both locations. However, it was more than 5.5 times likely at Mildura than Adelaide (1.30% for Mildura compared to 0.23% for Adelaide), as shown in Figure 1.

More *unprimed observations* below the landing minima (when conditions were forecast above the alternate minima) resulted from TAFs for Mildura Airport (8.3 hours per year) when compared to TAFs and TTFs for Adelaide Airport, as shown in Table 1. However, TAFs for Mildura Airport also had the lowest proportion of observations below the landing minima that were unprimed (7.3%), as shown in Figure 1.

Mildura Airport TAFs had a considerably larger percentage of false alarms (forecasts of weather below the alternate minima when weather conditions were observed above the alternate minima at the time of arrival) (13.25%) when compared with both TAFs (6.58%) and TTFs (4.96%) at Adelaide Airport.

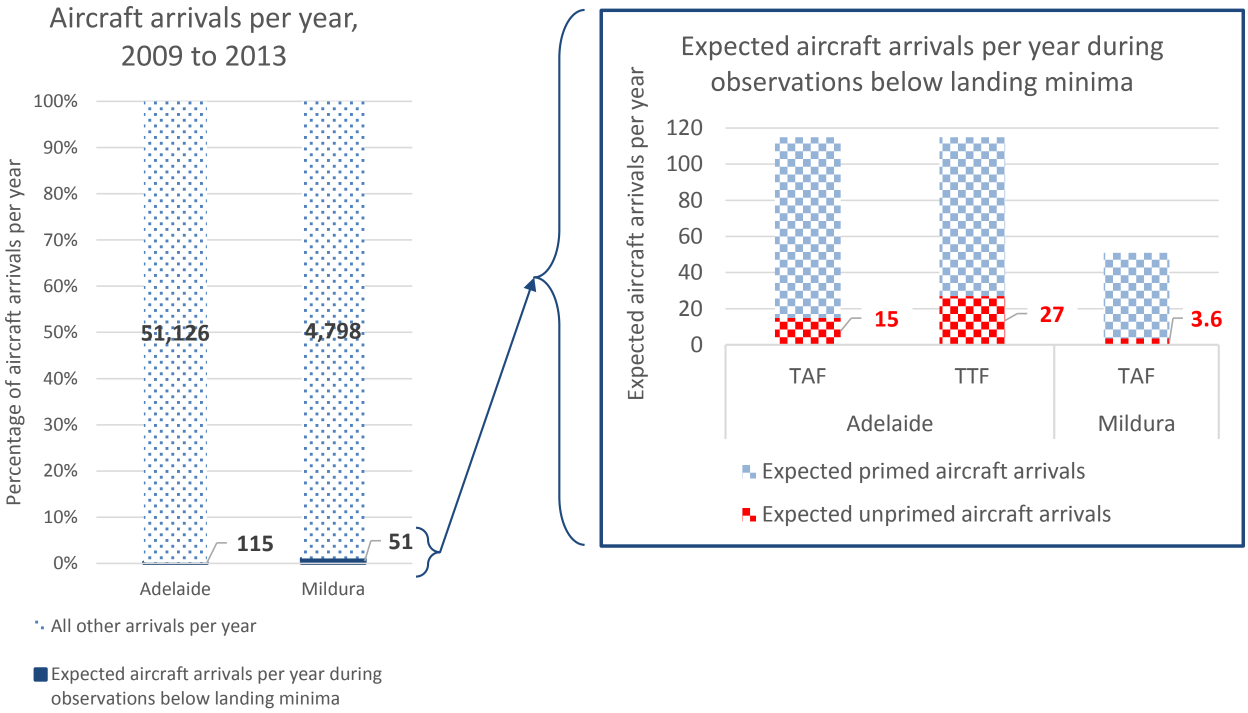
Figure 1: Observations below landing minima as a percentage of all time, and percentage of unprimed observations below landing minima for simulations averaged for retrieval 0 to 2 hours prior to arrival, Adelaide and Mildura Airports, 2009 to 2013



Despite having a lower likelihood of unsuitable landing conditions, more than twice the number of aircraft were expected to arrive at Adelaide Airport during observations below the landing minima compared to Mildura Airport (Figure 2). This is driven by Adelaide Airport having over 10 times more aircraft arrivals than Mildura on average (Table 1).

An average of 3.6 aircraft were expected to arrive at Mildura each year during unsuitable landing conditions without prior warning from a TAF, compared to 15 aircraft per year for Adelaide TAFs. Pilots retrieving TTFs for Adelaide were expected to arrive the most often during unprimed observations below the landing minima. However, the number of expected arrivals with false alarms was relatively lower for TTFs compared to TAFs.

Figure 2: Expected aircraft arrivals per year during observations below the landing minima, for simulations averaged for forecast retrieval 0 to 2 hours prior to arrival, Adelaide and Mildura Airports, 2009 to 2013



Analysis for Adelaide Airport

The analysis of TAF and TTF weather forecasts at Adelaide Airport between 2009 and 2013 found the following.

Overview of weather

On average, 17 weather episodes per year with unsuitable conditions for landing (below the landing minima) were identified at Adelaide Airport (86 in total):

- The duration of these weather episodes varied from a number of minutes, with minimal expected disruption to aircraft operations, to several hours. Half of all episodes had reported conditions for 30 minutes or more below the landing minima – these are expected to disrupt aircraft operations.
- Approximately 115 aircraft per year were expected to have planned arrivals during conditions below the landing minima. In 10 of the 86 episodes between 2009 and 2013, 15 or more aircraft per episode were expected to have a planned arrival during observations below the landing minima. The most significant episode having more than 50 expected aircraft arrivals.
- On average, the likelihood of arriving during reported conditions below the landing minima was only 0.23 per cent. However, the chances of arriving during these conditions changed considerably for different hours of the day and seasons in the year:
  - Weather below the landing minima was distinctly elevated between the hours of 0500 and 1100, and was mainly driven by fog and to a lesser extent, mist.
  - June to August (driven by fog) and December (driven by thunderstorms) were the most common months for unsuitable landing conditions.

Thunderstorms were the most common mechanism for conditions below the landing minima. They were reported in more than half of these weather episodes - an average of 10 episodes per year:

- Half of all thunderstorm episodes lasted for longer than 30 minutes.

- About 58 aircraft per year were expected to have planned arrivals during thunderstorms.
- With the exception of rain, thunderstorms were not generally associated with any other landing minima criterion or weather phenomena.
- Thunderstorms were generally observed throughout all hours of the day and months of the year. However, thunderstorms were elevated in September, November and December, and were more commonly observed from 1400 in the afternoon through to a peak between 2100 and 2200 in the evening.

Low cloud (weather episodes with conditions below the landing ceiling) was generally observed for a considerably longer duration below the landing minima when compared with other landing minima criteria:

- Although only involving about 3 episodes per year (14 in total), half of the episodes involving low cloud lasted for longer than 1 hour and 40 minutes below the landing minima ceiling.
- Low cloud was commonly observed in association with visibility below the landing minima.
- Around 40 aircraft per year were expected to have planned arrivals during conditions below the landing visibility or low cloud (below the landing ceiling).
- Fog was reported in all instances where both low visibility and low cloud at Adelaide were observed at the same time.

Fog had the longest median duration of all phenomena when conditions were below the landing minima, with half of all fog below minima being reported for longer than 1 hour 11 minutes:

- Fog was the second-most prevalent phenomena behind thunderstorms with around 6 hours per year.
- Fog also had the largest variation with the typical range from 8 minutes to 2 hours 24 minutes.
- Low cloud, patches of fog and fog partially covering Adelaide airport were often observed during the deterioration or improvement of fog covering the majority of the aerodrome. As a result, conditions were generally below the landing minima for longer than the fog alone.
- Fog below the landing minima was mainly observed between midnight and midday, almost entirely in the months from May to August.
- Distinct peaks of fog were observed between 0600 and 0700, and 0800 to 0900, with more fog occurring in the months June through to August.

During high wind (tailwind or crosswind above specified limits), the combination of wind directions favouring runways with approaches with higher minima when visibility and / or clouds were also below the landing minima had an effect. In these situations, it is not possible to land without breaching at least one landing minima criterion, however, *fewer* criteria are exceeded by accepting a landing above the nominated aircraft wind limitations:

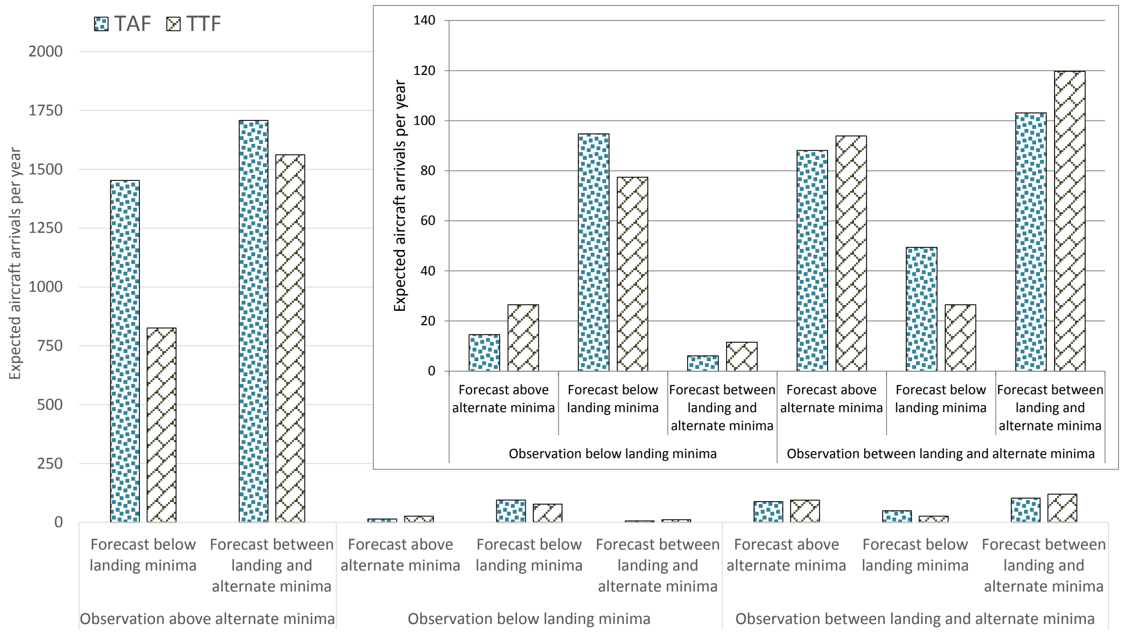
- Observed tailwind above 10 knots affected about eight planned aircraft arrivals per year at times where using the only runway within visibility and ceiling limits would have required a downwind landing. This was more common using the runway 23 instrument landing system which is the ideal approach for visibility and ceiling at Adelaide.
- These scenarios were identified during rain, mist and low cloud.
- Although most of these conditions had a relatively short duration (less than 25 minutes), five episodes had durations of longer than 30 minutes below the landing minima.

The effect of forecasts on aircraft operations

Comparisons were performed between reported observations (METARs and SPECIs) and forecast predictions (TAFs and TTFs). Simulated forecast retrievals between 0 and 2 hours prior to arrival (in 15 minute intervals) were used to estimate the likelihood of flight crews retrieving an unprimed forecast. This time frame was expected to provide the best case scenario for forecast retrieval.

The number of expected aircraft arrivals each year for all combinations of forecasts and observations are shown in Figure 3. That is, above the alternate minima, between alternate and landing minima, and below landing minima (except when both forecast and observations were above the alternate minima). This assumes the crew are using forecasts from either the TAF or TTF, but not both. The inset graph on the right of Figure 3 shows an expanded scale of observed conditions below the alternate minima. The left side of the graph shows when the forecasts were false alarms as observations were above the alternate minima.

Figure 3: Expected distribution of aircraft arrivals per year for sole use of TAF or TTF forecasts, simulations averaged for retrieval 0 to 2 hours prior to arrival (excluding correct rejections), Adelaide Airport 2009 to 2013



Unprimed observations below the landing minima (when conditions were forecast above the alternate minima) were very rare for both TAFs and TTFs (0.03% and 0.05% of the time respectively):

- TAFs were more conservative than TTFs as indicated by a lower likelihood of unprimed observations and a higher likelihood of false alarms (6.6% TAF, 5.0% TTF).
- When conditions were observed below the landing minima, 1 in every 7.7 minutes of active TAFs and 1 in every 4.3 minutes of active TTFs predicted conditions above the alternate minima.
- These occurred, on average, once in every 55 days for TAFs and once in every 38 days for TTFs.
- In all but two of the 56 individual unprimed episodes for simulated TAF or TTF retrievals 2 hours prior to arrival, TTFs had the same or longer (24 episodes) duration of unprimed observations.
- It was common for unprimed TAFs and TTFs to be observed on the same day.
- Fifteen aircraft per year, if using a TAF, would be expected to arrive at Adelaide during an unprimed observation below the landing minima (based on averaged simulations of TAF retrievals 0 to 2 hours prior to arrival).
- Twenty-seven aircraft per year, if using a TTF, would be expected to arrive at Adelaide during an unprimed observation below the landing minima (based on averaged simulations of TTF retrievals 0 to 2 hours prior to arrival).

- On average, there were 9.7 unprimed weather episodes per year using TTFs and 6.6 unprimed weather episodes per year for TAFs. These weather episodes ranged from less than 10 minutes to more than 4 hours.
  - This equates to 1 episode with an unprimed observation below the landing minima in around 5,000 arrivals for TTFs, and 1 episode in 7,700 arrivals for TAFs.

Thunderstorms and rain were the reason for most expected aircraft arrivals during unprimed observations (TAFs - 10 aircraft per year, TTFs - 15 aircraft per year), followed by fog/mist/low cloud (TAFs – 4 aircraft per year, TTFs – 11 aircraft per year).

- The largest difference in unprimed TAFs and TTFs were found for observations of fog/mist/low cloud.

False alarms (including fine weather periods surrounded by conditions below the alternate minima) created the largest operational differences between forecast types (TAFs or TTFs):

- A difference of around 773 more aircraft per year were expected to arrive at Adelaide with false alarms if only using TAFs instead of TTFs (following the stipulated rule sets for each forecast).[6]

About 90 aircraft per year would be expected to arrive during conditions between the landing and alternate minima without warning from a forecast (88 for a TAF, 94 for a TTF) (based on forecasts retrieved 0 to 2 hours prior to arrival). This indicates where the safety buffer between the alternate and landing minima values of ceiling or visibility has positive safety benefits.

Time of day and month

In general, the time of day and time of year significantly affect the likelihood of retrieving an unprimed forecast at Adelaide.

Figure 4 shows both unprimed (solid columns) and primed (transparent columns) observations below the landing minima across the 24 hours of the day (for simulated TAF and TTF retrieval averaged from 0 to 2 hours prior to arrival). It also shows the expected number of aircraft arrivals during unprimed observations (shading).

Unprimed TAFs and TTFs produced a similar pattern of expected aircraft arrivals by hour (shown as the hatched area in Figure 4):

- The largest number of aircraft arrivals during unprimed observations was expected between 1000 and 1200, for both TAFs and TTFs, with other elevated periods observed from 0800 to 1000 and 1400 to 2200.
- The lower number of expected aircraft arrivals during unprimed observations in the early hours (midnight to 0600) was related to a general period of reduced aircraft traffic. In contrast, less unprimed weather observations and in general a lower proportion of weather below the landing minima contributed to the lower number of expected aircraft arrivals during unprimed observations between 1200 and 1400.

Independent of aircraft arrival activity, the most common times of the day with unprimed observations (for a forecast retrieved 0 to 2 hours prior to arrival) were 1000 to 1200, and 2100 to 2200 for TAFs, and 0500 to 0700, 1000 to 1200 and 2100 to 2200 for TTFs (shown as solid columns in Figure 4):

- The largest differences between TAFs and TTFs were identified in the morning. This was mainly due to peaks of unprimed fog/mist and low cloud over the general baseline of unprimed thunderstorms. Differences between unprimed observations during thunderstorms and rain were more evenly distributed between TAFs and TTFs by hour of day.

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[6] TAFs have associated 30 minute timing buffers added to any prediction below the alternate minima, as covered in *Stipulated contingency plans* on page 21.

In contrast to the main weather peak period below the landing minima of 0500 to 1000 (columns in Figure 4), periods surrounding the main weather peak period had the largest proportion of unprimed observations for TAFs and TTFs when compared to the total duration of conditions below the landing minima. These were between 0400 and 0600, and 1000 to 1100:

- These corresponded to the main period of fog, mist and low cloud.
- While the fog, mist and low cloud appear to be more readily predicted at peak times, determining when the weather will start and how long it will remain appears to be more problematic.
- Additionally, thunderstorms had the least reliable percentages of any unprimed observations for both TAFs and TTFs between 0300 and 0400, and between 0900 and 1000.

Across the day, TTFs had consistently higher proportions of observations below the landing minima that were unprimed (0 to 40 per cent) than TAFs (0 to 30 per cent). This is in line with general observations.

Figure 4: Hours active forecasts were available for unprimed and primed observations below the landing minima (columns), thousands of aircraft arrivals (blue line), and expected aircraft arrivals during unprimed observations below the landing minima (shading) per year, by hour of day, averaged for simulated TAF and TTF retrieval times between zero to 2 hours prior to arrival 2009 to 2013. Column labels indicate the number of weather episodes per year for each category and are additive.

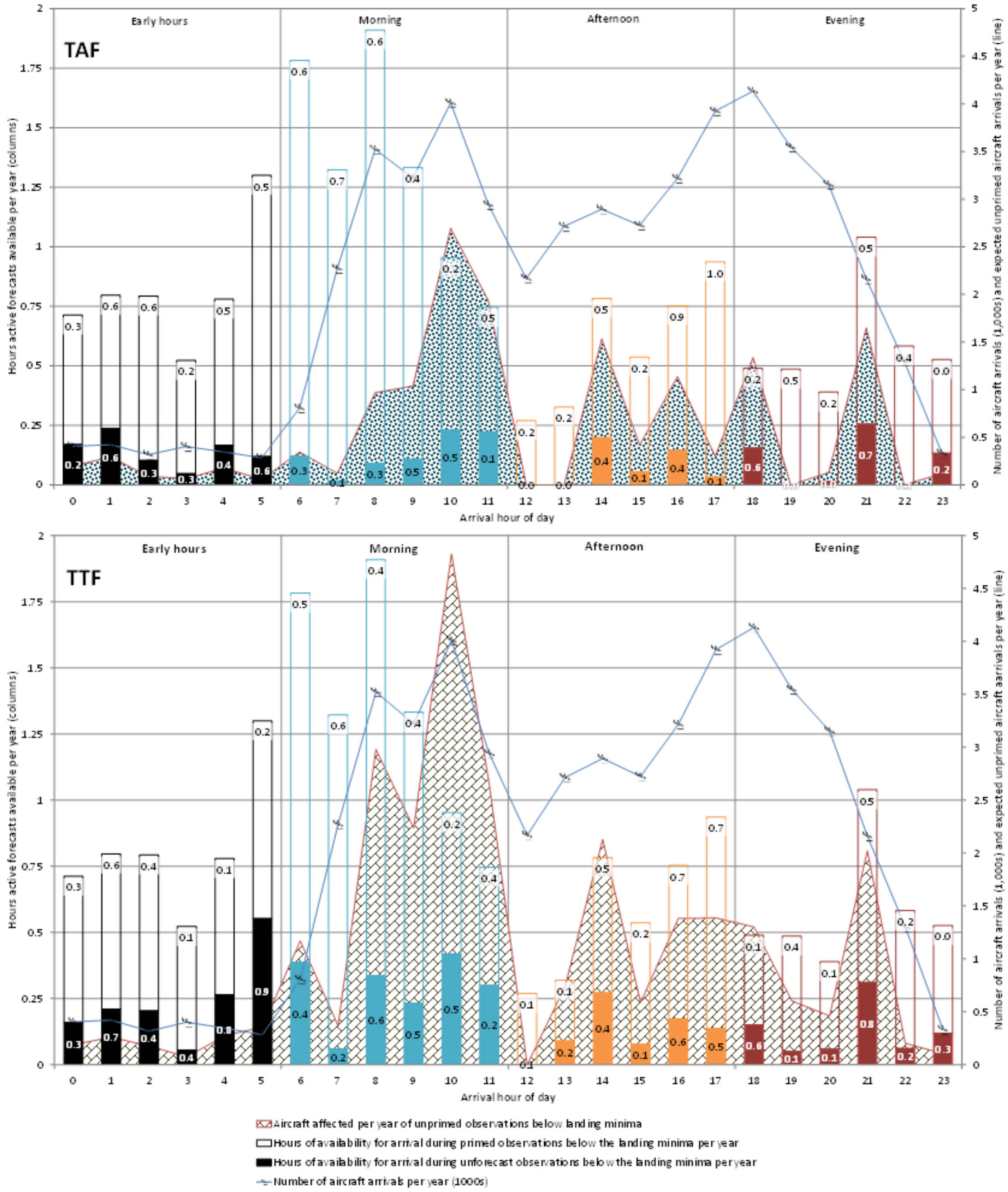


Figure 5 shows the same types of information as Figure 4 by month and quadrant of day.

The highest peak in the number of expected aircraft arrivals during unprimed observations were in mornings in June (generally between 0800 and 1200 and particularly between 1000 and 1100) for both TAFs (5.5 arrivals per year) and TTFs (8.8 arrivals per year):

- June mornings (0600 to 1200) also had the longest duration and highest percentage of unprimed observations (for TAFs and TTFs) when compared to total observations below the landing minima.
  - 27.0 per cent of observations below the landing minima were unprimed for TAFs (31 minutes unprimed out of 113 minutes per year).
  - 45.0 per cent of observations below the landing minima were unprimed for TTFs (51 minutes unprimed out of 113 minutes per year).
- June was simulated to have an average of 1.8 unprimed episodes for TTFs per year.
- This time of year would probably benefit most from improved forecasting at Adelaide.

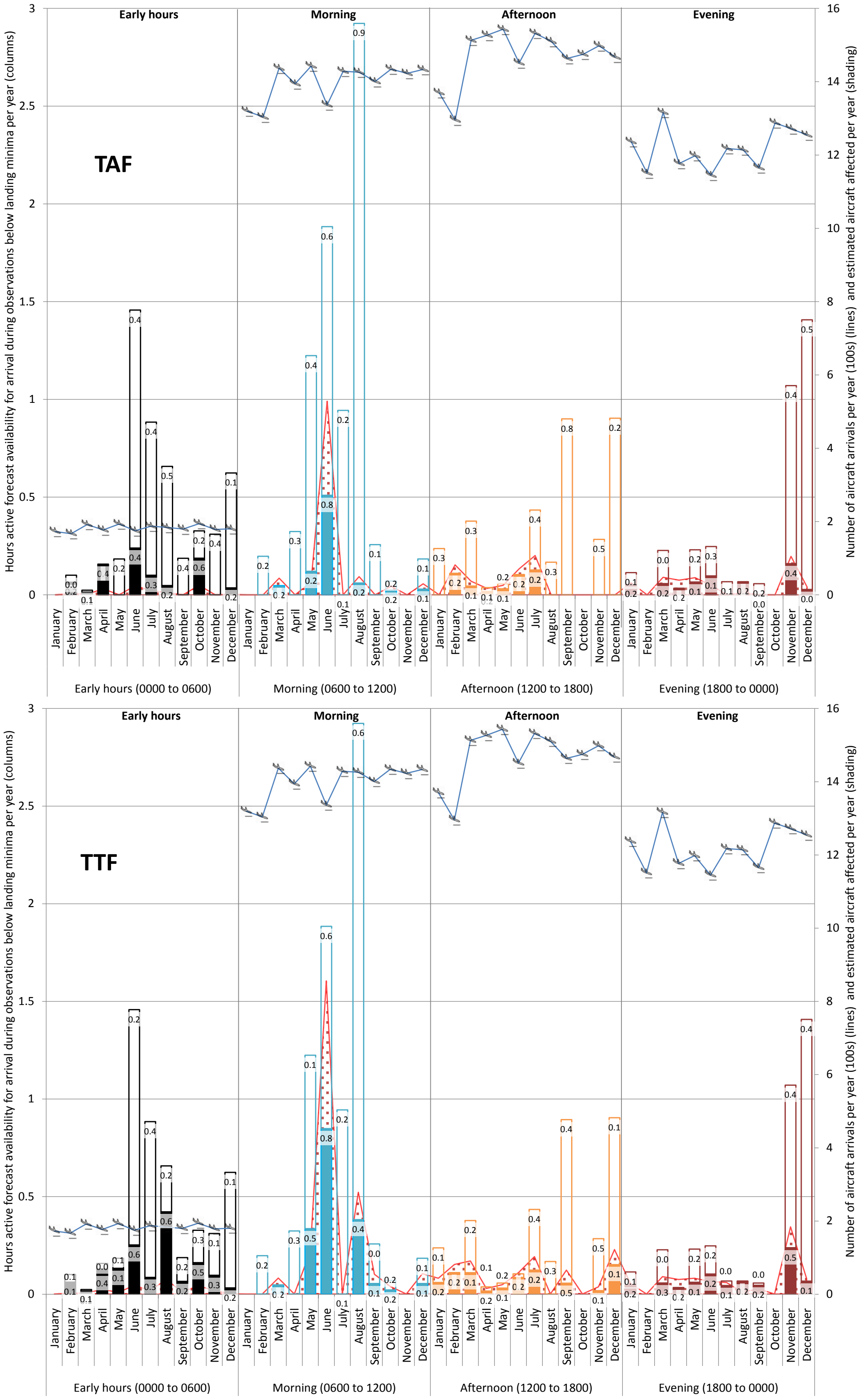
Evenings in November (particularly between 2100 and 2200) also had elevated expected aircraft arrivals during unprimed observations for TAFs and TTFs.

In addition, November evenings had a relatively high percentage of all observations below the landing minima that were unprimed for TTFs (22.2 %). This was also the case for mornings in May (particularly between 0600 and 0700) (27.3%) and mornings in August (particularly between 1000 and 1100). August mornings also had a relatively higher number of expected aircraft arrivals during unprimed observations.

There were no unprimed observations from February to May between 1900 and midnight for TAFs or TTFs. Additionally, TAFs had no unprimed observations identified between 1200 and 1900 from August through to January in any year.

Unprimed fog, mist and low cloud in August, June and May had the largest differences between unprimed TAFs and TTFs compared to other months. June was also the least reliable time for predicting thunderstorms for both TAFs and TTFs.

Figure 5: Hours active forecasts were available for unprimed and primed observations below the landing minima and expected aircraft arrivals during unprimed observations per year, by month for each quadrant of day, averaged for forecast retrieval times between zero to 2 hours prior to arrival 2009 to 2013 (other data descriptions as per Figure 4)



Aircraft affected per year of unprimed observations below landing minima
Hours of availability for arrival during primed observations below the landing minima per year
Hours of availability for arrival during unforecast observations below the landing minima per year
Number of aircraft arrivals per year (100s)

The year 2013 had the highest number of aircraft expected to arrive with unprimed weather conditions below the landing minima (using either a TAF or TTF). This was driven largely by the weather episode on 18 June 2013 and a slight increase in aircraft activity compared to earlier years.

Duration and effect of unprimed observations

The median average unexpected holding time when arriving at Adelaide with unprimed observations was 14 minutes using a TAF and 24 minutes using a TTF.

TAFs were found to produce a lower overall unexpected holding time[7] per episode with unprimed observations when compared with TTFs.

Most of the time, estimated unexpected holding times were less than 30 minutes following arrival during unprimed observations for both TAFs and TTFs. However, throughout the day, particularly in the morning, there have been weather periods when the estimated holding was longer than standard fuel reserves of arriving aircraft (usually between 20 and 45 minutes):[8]

- Unexpected holding times of more than 30 minutes were predicted for a number of quadrants of day. Notably:
  - In the morning (0600 to 1200), 53 per cent of the time when arriving with unprimed observations from a TTF and 36 per cent of the time for a TAF.
  - In the early hours (midnight to 0600), 27 per cent of the time when arriving with unprimed observations from a TTF and 15 per cent for a TAF.

Following periods of degraded weather at Adelaide, a traffic queue may have developed lengthening the holding time due to the maximum aircraft acceptance rate of the airport.

Forecast retrieval time comparisons

Forecasts' decay in accuracy over time. That is, the number of unprimed observations for both TAFs and TTFs increases as the retrieval time prior to arrival is increased.

Generally, TTFs had more rapid decay than TAFs (the chance of unprimed observations below the landing minima increased more rapidly as the simulated retrieval time prior to arrival was increased):

- Unprimed fog and mist steadily increased with simulated retrieval time prior to arrival (up to just under 70 per cent of all fog/mist below the landing minima 12 hours prior to arrival for TAFs, and just over 40 per cent of all fog/mist below the landing minima 150 minutes prior to arrival for TTFs).
- Unprimed thunderstorms also increased for simulated retrievals to the end of the effective TTF duration (up to around 45 per cent of all thunderstorms at 150 minutes prior to arrival). For TAFs, the increase stabilised after 6 hours (about 40 per cent of all thunderstorms).

From the perspective of operational decision making, it is relatively more important that forecasts are retrieved at the latest possible time prior to arrival (before the point the aircraft can divert to an alternate airport) in the early hours and morning compared to the afternoon and evening where the forecast retrieval time prior to arrival has less impact:

- The differences in the decay of forecasts over time from the early hours and morning to the afternoons and evenings probably relates to forecasting of low cloud, fog and mist, over a baseline of thunderstorms.

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7 Estimated unexpected holding time is the time that an aircraft is estimated to expectantly hold following arrival in conditions below the landing minima after the retrieval of a forecast above the alternate minima.

8 An additional variable reserve of up to 15 per cent applies to some aircraft – see Civil Aviation Advisory Publication CAAP 234-1, *Guidelines for aircraft fuel requirements*, for details.

Expected aircraft arrivals with unprimed observations increased considerably in the morning (particularly for TTFs) as the simulated retrieval time prior to arrival became longer:

- For TTFs, an increase from 11 up to 21 arrivals was expected as simulated TTF retrieval times increased from 30 to 150 minutes prior to arrival. For TAFs, the equivalent retrieval time was 7 hours prior to arrival for an expected 21 arrivals per year.
- For TAFs, a substantial climb in the number of expected aircraft arrivals from less than 4 per year at the time of arrival, up to 34 per year if all TAFs were retrieved 12 hours prior to arrival. This is an increase of about 2.3 aircraft arrivals per year for each additional retrieval hour.

If a company flew a single aircraft to Adelaide every day of the year, and always arrived in the mornings, they are likely to arrive with an unprimed observation below the landing minima:

- about once every 7.2 years using TAFs and once every 3.3 years using TTFs if they are retrieved 1 hour before arrival
- about once every 4.6 years using TAFs and once every 2 years hours using TTFs if they are retrieved 2.5 hours before arrival
- about once every 3.9 years if they retrieve TAFs 4 hours before arrival
- about once every 22 months if they retrieve TAFs 9 hours before arrival
- about once every 16 months if they retrieve TAFs 12 hours before arrival.

The likelihoods above were around 3 times higher applying the above scenario to arrival between 1000 and 1200 only.

Early hours (midnight to 0600) had similar probabilities of unprimed observations as the morning, although there are very little aircraft arrivals during these hours.

Unprimed observations in afternoons appear to asymptote when a TAF is retrieved longer than 3 hours prior to arrival. Evenings also stabilised when a TAF was retrieved longer than 6 hours prior to arrival.

The median average holding time increased in the mornings with an increase in retrieval time prior to arrival. This was relatively stable for the remaining quadrants of the day. The median holding time was less than 30 minutes for both TAFs and TTFs in all quadrants, however, as stated above, a number of episodes were identified with periods of holding exceeding standard fuel reserve limits.

Characteristics of unprimed observations

The largest differences between TAFs and TTFs for unprimed conditions were for low cloud (ceiling) and thunderstorms:

- Unprimed ceiling observations below the landing minima were observed around 90 minutes per year for TTFs, and 22 minutes per year for TAFs, with 10 and 3.5 expected aircraft arrivals respectively during these times.
- About 11 aircraft were expected to arrive during unprimed thunderstorms when using TTFs, while 6 aircraft were expected when using TAFs.
- Just over 1 in every 5 minutes of thunderstorms, visibility and ceiling below the landing minima were unprimed for TTFs. In contrast, TAFs had much lower proportions of conditions that were unprimed: visibility (1 in 9 minutes), thunderstorms (1 in 7 minutes) and ceiling (1 in every 20 minutes).

Weather episodes where observations below the landing minima started in an unprimed state later became primed (about 2.9 episodes per year for TAFs and 5.6 episodes every year for TTFs averaged between 0 to 2 hours prior to arrival). Most of these periods were ‘recovered’ by the release of an amended TAF or a TTF attached to a SPECI.

The systemic reaction time to amend a forecast following unanticipated observations below the landing minima were assessed for TAFs and TTFs. For TAFs, these scenarios generally resulted in the released of an amended TAF:

- In just over 3 episodes per year, amended TAFs were released prior to the first observation below landing minima.
- For episodes starting with an unprimed observations, the median reaction time to recover (by releasing an amended TAF) was 35 minutes (2 episodes per year).
- Most amended TTFs recovering an unprimed observations based on the previous TTF were released as part of the SPECI reporting the first conditions below the landing minima in an episode (4.4 episodes per year). This contributed to a rapid degradation of TTF reliability as forecast retrieval time prior to arrival increased.

Alternate versus landing minima

Using forecast conditions between the landing and alternate minima for operational decision making, instead of conditions above the alternate minima, considerably increases chances of arriving during unprimed observations below the landing minima:

- If the landing minima was used instead of the alternate minima:
  - For TAFs, 21 aircraft arrivals with unprimed observations below the landing minima per year would be expected (1.42 times the number when using the alternate minima). Additionally, unprimed observations would increase from 13 to 19 per cent of all observations below the landing minima.
  - For TTFs, 39 aircraft arrivals with unprimed observations per year would be expected (1.47 times the number when using the alternate minima). Unprimed observations would increase from 23 to 37 per cent of all observations below the landing minima.
- This shows that at typical times of day at Adelaide where a flight crew may be approaching a point of not being able to divert to an alternate airport between 0 and 2 hours prior to arrival, the chances of arriving during conditions below the landing minima are increased (1.45 times for TAFs, 1.55 times for TTFs) when relying on the forecast landing minima compared with the alternate minima.

The alternate minima criteria for visibility and ceiling appear to be positioned at relatively stable values, with only slight benefit or loss from small perturbations.

Conclusions for Adelaide Airport analysis

- TAFs were more conservative when compared with TTFs at Adelaide as indicated by a lower likelihood of unprimed observations (0.03% TAF and 0.05% TTF) and a higher likelihood of false alarms (6.6% TAF, 5.0% TTF).
- Fifteen aircraft arrivals during unprimed observations at Adelaide were expected if TAFs were solely used compared to 27 aircraft if TTF were solely used. False alarms were expected to result in 773 more aircraft arrivals if using TAFs instead of TTFs.
- It is relatively more important that forecasts are retrieved at the latest possible time (before the point of no diversion) prior to arrival in the early hours and morning compared to the afternoon and evening where the forecast retrieval time prior to arrival has less impact. The highest peak in the number of expected aircraft arrivals during unprimed observations were in mornings (generally between 0800 and 1200 and particularly between 1000 and 1100).
- For TAFs, an increase of 2.3 aircraft arrivals during unprimed observations per year can be expected for every additional hour prior to arrival that a TAF was retrieved (4 aircraft per year for retrieval at the time of arrival up to 34 aircraft arrivals per year for retrievals 12 hours prior to arrival). TTFs increased from 11 up to 21 arrivals during unprimed observations when retrieving the TTF from 30 to 150 minutes prior to arrival.

- Unexpected holding times of more than 30 minutes were predicted for a number of quadrants of day. Notably, in the morning, 53 per cent of the time using TTF, and 36 per cent using TAF, resulting in holding more than 30 minutes when arriving in unprimed observations.
- Using forecast conditions between the landing and alternate minima for operational decision making instead of conditions above the alternate minima considerably increases chances of arriving during unprimed observations below the landing minima. For example, using the landing minima as a threshold increases the chances of arriving during unprimed observations below the landing minima by 45 percent for TAFs and 55 per cent for TTFs.

Analysis for Mildura Airport

The analysis of weather forecasts (TAF only) and observations at Mildura Airport between 2009 and 2013 found the following.

Overview of weather

On average, one in ten days had some period where observations were below the landing minima, with half of these episodes lasting for more than 90 minutes.

- Two-thirds involved reduced visibility, one-third involved low cloud (ceiling), and one-quarter involved thunderstorms.
- The peak time of the day for observations below the landing minima was between 0400 and 1000 (0700 had 12 hours per year), due to visibility and a lesser extent, ceiling, from both fog and/or mist. Thunderstorms were evenly spread across the day (1 hour per year each hour), but peaking at 1600 with 2 hours per year.
- Peak observations below the landing minima were in winter months (18 hours per year in July) from visibility and ceiling. Thunderstorms centred on summer months.

Overall, it was rare for observations to be below *alternate* minima (2.6 per cent of the time), or below the *landing* minima (0.99 per cent of the time).

Forecasts of observations below the landing minima

Unprimed observations below the landing minima (when conditions were forecast above the alternate minima) were very rare (0.09% of the time). (In contrast, false alarms occurred 13 per cent of the time where forecast were below alternate minima but actual weather conditions were observed above the alternate minima):

- However, when conditions were observed below the landing minima, 1 in every 10 minutes of active forecasts predicted conditions above the alternate minima.
- This was equivalent to about 8 hours of unprimed observations per year (with discrete episodes every 38 days on average).
- Taking into account when aircraft arrive and when the unprimed observations were recorded, on average, about 4 aircraft arriving at Mildura were affected each year by unprimed observations below the landing minima, ranging from 1 aircraft in 2012 to eight in 2013.

Weather observations were unprimed mostly due to the forecasting starting late (especially from forecasts up to 2 hours prior to arrival time), followed by the observations not being predicted at all (especially for forecasts longer than 2 hours prior to arrival). When considering forecasting that started late, the median delay from the first unprimed observation to the release of the amended TAF was about 10 minutes, providing an indication of the systemic reaction time.

The times between and around 1000 to 1100 were the most significant time of day when considering the combination of aircraft arrivals and periods of unprimed weather observed below the landing minima. This peak was mostly driven by unprimed observations below the ceiling minima.

Mornings (0600 to 1200) had the most arrivals, and 2.4 hours of unprimed observations per year, resulting in the most expected aircraft arrivals during unprimed observations (2.2 per year). This centred on 1000. Afternoons (1200 to 1800) had very little unprimed observations, while evening (1800 to midnight) and early hours (midnight to 0600) had very low arrivals, resulting in low estimations of aircraft arrivals during unprimed observations each year (1.0, 0.4 and 0.1 respectively):

- Although having less effect on aircraft due to arrival timings, late evenings and early hours saw higher proportions of observations below the landing minima being unprimed (forecast above the alternate minima).
- Unprimed observations in the mornings were more common in the winter months, and mornings in the winter had the most effect on arriving aircraft (about 1.5 aircraft affected each year in July mornings alone). In particular, 1000 in July was a hotspot.
- Fifty-eight per cent of the duration of unprimed observations following aircraft arrival in the early hours had an average holding time greater than 75 minutes, the highest of all quadrants of the day. For the morning quadrant, 64 per cent of arrivals with unprimed observations were longer than 30 minutes, and 49 per cent were longer than 45 minutes. In contrast, the afternoon and evening had even lower estimated holding times, with smaller variation, with less than half of all these arrivals periods having an estimated holding time of more than 30 minutes.
- A number of months had at least half of the estimated holding times for arrivals with unprimed observations greater than 30 minutes in duration, notably September (47 minutes), January and August (both 43 minutes), and July (31 minutes).
- The combination of expected aircraft arrivals (likelihood) and holding time (severity) can be used to provide an indication of the relative risk by month that unprimed observations have on aviation safety. July had the largest number of expected aircraft arrivals, stemming from the largest number of unprimed observations below landing minima during the high morning air traffic period.

Although many observed conditions had durations of half an hour or less (both unprimed and primed), more than half had conditions below the landing minima for more than 75 minutes.

In the early hours and morning quadrants, retrieving a forecast earlier before arrival will increase the likelihood of arrival during unprimed observations below the landing minima:

- For the mornings (0600 to 1200), retrieving a forecast 60 minutes before arrival resulted in a 0.1 per cent chance of arriving during unprimed observations. This increases to 0.35 per cent chance if the forecast was retrieved 5 hours before arrival.
- That is, if a company flew a single aircraft to Mildura every day of the year, and always arrived in the mornings, they are likely to arrive with unprimed observations below the landing minima:
  - about once every 2.5 years if they retrieve forecasts 1 hour before arrival
  - about once every 18 months if they retrieve forecasts 2 hours before arrival
  - about once every 15 months if they retrieve forecasts 3 hours before arrival
  - about once every 11 month if they retrieve forecasts 4 hours before arrival
  - about once every 9 months if they retrieve forecasts 5 hours before arrival.
- In the afternoon and evening, the forecast retrieval time prior to arrival had minimal impact.
- From the perspective of operational decision making, this shows that in the early hours and morning, it is relatively more important that forecasts are retrieved at the latest possible time prior to arrival (before the point of no diversion). However, in the afternoon and evening, the forecast retrieval time prior to arrival has minimal impact.

Characteristics of unprimed observations

Each year, there were about 6 hours of unprimed observations below the visibility landing minima (which affected slightly less than 2 aircraft), while only 2.5 hours under the cloud (ceiling) minima (which affected slightly more than 2 aircraft per year). There was less than 1 hour a year with unprimed thunderstorms (affecting 1 aircraft per year). Crosswind had minimal effect (about 1 aircraft every 5 years).

Using forecast conditions between the landing and alternate minima for operational decision making instead of conditions above the alternate minima considerably increases chances of arriving at Mildura during unprimed observations below the landing minima:

- For *any* TAF that was retrieved 0 to 6 hours prior to arrival , if the landing ceiling criterion was used for decision making instead of the alternate ceiling at Mildura, there was at least 20 times more chance of arriving during observations below the landing ceiling than when relying on the alternate minima threshold.
- If the landing visibility criterion was used for decision making instead of the alternate visibility, the chance of arrival during visibility below the landing minima was an average of 16 times greater for forecast retrievals up to 90 minutes prior to arrival. At 6 hours prior to arrival, the likelihood was still notably higher at 7 times more likely.
- Furthermore, if the landing minima was used instead of the alternate minima, this would result in 13.6 aircraft being affected per year (3.7 times the expected number when using the alternate minima). Unprimed observations would increase from 7 to 26 per cent of all observations below the landing minima.
- This shows that at typical times of day at Mildura where a flight crew may be approaching a point of no diversion between 0 and 2 hours prior to arrival, the chances of arriving during conditions below the landing minima are considerably increased when relying on the forecast landing minima compared with the alternate minima.

The alternate minima criteria for visibility and ceiling appear to be positioned at relatively stable values, with only slight benefit or loss from small perturbations.

Conclusions for Mildura Airport analysis

- Overall, it was rare for observations to be below *alternate* minima (2.6 per cent of the time), or below the *landing* minima (0.99 per cent of the time).
- Unprimed observations below the landing minima were very rare (0.09 per cent of the time).
- The times between and around 1000 to 1100 were the most significant time of day when considering the combination of aircraft arrivals and periods of unprimed weather observed below the landing minima.
- Mornings (0600 to 1200) had the most arrivals, and 2.4 hours of unprimed observations per year, resulting in the most aircraft affected by unprimed observations (2.2 per year). This centred on 1000.
- In the early hours and morning quadrants, retrieving a forecast earlier before arrival will increase the likelihood of arrival during unprimed observations below the landing minima.

Context

Over the past 15 years, a number of unforecast weather episodes relating to flights into major Australian airports have led to unforeseen diversions, holding, and in some cases, landing below published safe limits.[9] This research investigation was initiated as a result of these occurrences, and because of the limited amount of Australian-based research in this area. The objective of this research was to understand how the reliability of weather forecasts affects the ability of flight crew to conduct safe landings at Australian airports.

One occurrence, on 18 June 2013, involved two Boeing 737-800 aircraft that encountered unforecast weather en route to Adelaide leading to a diversion to Mildura Airport, Victoria. Upon arrival, both aircraft encountered weather unsuitable for landing. Both aircraft landed in conditions below the published safe limits, with one aircraft also landing in a fuel critical state (ATSB occurrence investigation AO-2013-100).

Due to the involvement of Adelaide and Mildura Airports in the above occurrence, the current research report covers the operational reliability of weather forecasting of these airports. This is the first report in a planned series covering Australian airports supporting regular public transport operations.

To identify how weather forecasting at individual airports can potentially impact on safety, a comparative analysis was conducted between all aviation weather forecasts and coinciding reported observations. A further aim was to understand the effects that weather forecasting can have on aircraft engaged in air transport-related operations, specifically how weather forecasting may affect safe landing at airports.

For Adelaide and Mildura, forecast and observation data were provided from the Australian Bureau of Meteorology (BoM) between 2009 and 2013. Aircraft arrivals data were provided for each hour between 2010 and 2013 by Airservices Australia and were used as the basis for modelling expected aircraft arrivals. This analysis focussed on identifying forecasts that did not provide sufficient indication to flight crews and other operational personnel when reported conditions were unsuitable for an aircraft to land. An aircraft arrivals model was then used to estimate the number of aircraft expected to arrive during these times.

[9] ATSB investigations of incidents related to unforecast weather include: 199904029, 200401270, 200605473, AO-2012-073, AO-2015-067, and AO-2013-100, available on the ATSB's website at www.atsb.gov.au.

Background

Limits of a safe landing

Where there is less than visual meteorological conditions[10] (VMC) at an airport, there are visibility limitations that affect the ability of pilots to land their aircraft – these are instrument meteorological conditions (IMC). The ability to land at a nominated airport in IMC can be influenced by the following main elements:

- aircraft and aerodrome navigational equipment (including aircraft navigational instrumentation and aerodrome radio navigational aids)
- published instrument approach procedures
- aircraft performance limitations.

The combination of these elements are used to define if an aircraft is able to land given certain weather conditions.

Aircraft and aerodrome navigational equipment

To land in conditions of reduced visibility or low cloud, a combination of aircraft and aerodrome navigational equipment can be used to guide an aircraft toward and in-line with a runway without visual reference to the ground. The more precise and reliable the equipment, the lower and closer to the runway an aircraft can fly.

The typical process of landing in adverse conditions involves an approach to a runway being flown without the pilots being able to see the runway. Descent continues solely using flight instruments until descending to a minimum allowable point. At that point, the landing will be aborted unless visual contact is established with the intended landing runway, where the approach to landing would be continued.

Navigational equipment ranges from less precise and simple non-directional (homing) beacons which may allow an aircraft to fly below a cloud base while still relatively high above the ground, to a sophisticated instrument landing system (ILS) allowing a flight crew to safely continue flight to considerably lower heights above the runway without visual reference.[11]

Most modern aircraft used by airlines in Australia are equipped with a vast array of instrumentation specifically designed to provide guidance for landing in adverse weather conditions.

Some of this equipment can be used without any ground-based reference, such as the use of a global navigation satellite system (*GNSS*). In contrast, some guidance equipment relies on radio communication from specifically designed aerodrome navigational aids, and some guidance is an augmented combination of the two. As such, both aircraft and ground equipment (if applicable) need to be present and operating to be used.

Major airports in Australia generally have a range of guidance equipment (radio navigational aids) on the ground to assist flight crews to make safe, precise and efficient landings. However, it is common for modern airliners to be fitted with more precise equipment than that provided by the existing aerodrome infrastructure.

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[10] Visual Meteorological Conditions is an aviation flight category in which visual flight rules (VFR) flight is permitted—that is, conditions in which pilots have sufficient visibility to fly the aircraft maintaining visual separation from terrain and other aircraft.

[11] At Adelaide Airport, the minimum height allowed for an ILS approach was 250 feet at the time of writing, however other systems such as Melbourne Airport are certified with no limit on the ceiling (i.e. the aircraft can safety land with cloud on the ground so long as visibility is above specified limits).

Published instrument approach procedures

Instrument approach procedures (IAPs) are produced for many Australian airports which describe required aspects of pre-determined flight paths when using selected navigational equipment. Each IAP is generally limited to an approach toward a particular runway[12] using one or more aircraft instruments paired with corresponding aerodrome navigational aids or a GNSS.

These published instrument approaches include two pertinent elements:

- the minimum height above the ground[13] that a flight crew can safety descend to (or decide to continue) prior to being required to abort the landing
- the minimum visibility.

The minimum allowable height and minimum visibility are referred to as landing minima criteria.

In most IAPs, the landing minima criteria depends on the specific landing speed of an eligible aircraft, and in some cases, aircraft design characteristics, such as the number of engines, the aircraft width and the aircraft range. In general, the faster and the larger the aircraft, the more stringent the landing minima published in an IAP will be.

Aircraft performance limitations

Modern aircraft are designed to be resilient against severe weather conditions during landing, with relatively high strength and controllability allowing landing in adverse conditions within safe limits. However, defined limits exist that are designed to ensure safe margins are maintained.

In relation to an aircraft conducting a landing, three main elements were considered in addition to those mentioned above:

- maximum demonstrated crosswind
- maximum tailwind
- thunderstorms.

Crosswind is the wind component blowing across the runway. The calculated maximum limit is determined by the aircraft manufacturer. The tailwind is the component blowing in the same direction as the aircraft. Tailwind has a significant effect on the ability to decelerate and stop after touchdown, because the aircraft's ground speed is the landing *airspeed* in addition to the strength of the tailwind component.

Thunderstorms at an aerodrome were also considered to produce unsuitable conditions for landing due to unpredictable and potentially damaging strong winds and associated weather.

For the purpose of this report, the landing minima criteria refer to the five bulleted points noted in the two sections above (visibility, ceiling, crosswind, tailwind and thunderstorms).

Meteorological observation reports below safe landing limits

Every day, thousands of aviation specific weather products are produced by the Australian Bureau of Meteorology (BoM) for use by the aviation industry. These weather products are disseminated to pilots through Australia's two air navigation service providers, Airservices Australia and the Royal Australian Air Force.

One type of product released is an aerodrome weather report, referred to as METARs (routine reports) and SPECIs (special reports). These may be used by flight crews to provide an indication of the observed conditions in the immediate past.

12 In some cases an approach can be flown toward an aerodrome to fly the aircraft below cloud to become visual and 'circle' to land at a runway of a favourable length or wind direction. This is referred to as a circling approach.

13 Referred to as either a decision altitude or minimum descent altitude depending on the type of approach.

METARs provide a representation of *observed conditions* near the time of release. Whenever conditions are below minima criteria or have recently improved, a SPECI is produced in lieu. These are generally released on a more frequent basis, and as such are expected to provide a more accurate representation of observed conditions compared to METARs.

Observations below safe landing limits

If weather conditions deteriorate below established limits for a safe landing, they are said to be *below the landing minima*. Landing minima are discussed in *Limits of a safe landing* on page 21. Conditions are considered to be below the landing minima when any of the following are observed at an aerodrome:

- low visibility
- low (cloud) ceiling (used to represent the minimum height above the ground)
- above aircraft maximum demonstrated crosswind
- above aircraft maximum tailwind
- presence of thunderstorms.

METAR and SPECI reports contain information to assess each of these criteria, which can be used by flight crew (and in this analysis) to indicate the suitability of conditions for landing.

Planning for a safe landing using aviation weather forecasts

A number of different types of aviation weather forecasts exist to help inform decisions for the conduct of safe and efficient operations at different phases of flight. These may be retrieved prior to flight for the purposes of flight planning for arrival at the planned destination at a particular time, or the planned passage through an area. Additionally, forecasts may be retrieved in-flight to check whether new forecasts exist predicting different conditions to those originally anticipated.

Two of these weather forecasts are aerodrome forecasts (TAFs) and trend forecasts (TTFs) which focus on weather up to 9 km (5 NM) from an airport. An important function of TAFs and TTFs is their use for the assessment of whether a contingency plan is required (see *Stipulated contingency plans* below). This is ultimately based on the expected likelihood that the aircraft may encounter adverse weather conditions.

TTFs are short term forecasts only available for major airports, including Adelaide, but not Mildura. In Australia, these are valid for 3 hours from the time of release, and in other parts of the world, these are typically available for 2 hours.

There are four different types of routine TAFs issued in Australia based on the size of an airport. These range from a category A international airport where forecasts are released every 6 hours with up to 30 hours validity, to a category D small aerodrome, where forecasts are released every 6 to 12 hours and are valid for a maximum of 12 hours.

- Adelaide is a category A (international) airport. TAFs are released every 6 hours, and are valid for 24 or 30 hours.
- Mildura is a category B (large) airport. TAFs are released every 6 hours, and are valid for 12 or 18 hours.

TAFs and TTFs are the only forecasts that are allowed to be used for the planning of a flight to conduct a safe landing.[14] These forecasts are designed to provide specific time and location based information for pilots and other operational personnel for arrivals at a planned destination, and if required, utilised to form specific contingencies if weather is forecast to be marginal.

[14] Aeronautical Information Publication ENR 1.1 59 – 18 August 2016.

TTFs take precedence over TAFs

For the purposes of flight planning, it is stated that a flight *may* be wholly planned with reference to the TTF for the planned destination, for the period of the flight that will be conducted within the TTFs validity period.[15]

However, for the purpose of this report, and although synchronised, TAFs and TTFs are analysed and compared independently in relation to the simulated operational effect.

Stipulated contingency plans

Inherently, forecasts are variable in the precision and timing of predictions. To account for this, systemic barriers are put in place.

During flight planning, published figures, referred to as 'alternate minima' are required to be used as decision thresholds for contingency planning. This means that if conditions are forecast to be below an alternate minima, a contingency plan is required. The alternate minima variables are the same five variables presented earlier (visibility, ceiling, crosswind, tailwind and thunderstorms).

A contingency plan generally takes the form of either:

- carrying sufficient fuel to fly to an alternate destination
- carrying sufficient fuel to hold until forecast adverse weather subsides
- delaying take-off in anticipation to arrive after adverse weather.

Visibility and ceiling alternate minima criteria are also contained in each instrument approach procedure (described in *Published instrument approach procedures* on page 22), and are higher (more conservative) than the landing minima values. This allows for some inaccuracy between forecast and observed conditions.

For example, the minimum visibility for landing using a particular instrument approach procedure may be 4,000 m, whereas the alternate applying to that aircraft may be 6,000 m, thereby allowing observed conditions to be up to 2,000 m *lower* than forecast before a flight crew would be left without a contingency plan.

Forecast thunderstorms and winds exceeding the maximum limits of the aircraft are also used in alternate minima. For strong winds, only conditions forecast above the maximum aircraft limits require contingency planning. Thunderstorms only have two possible states, existence or not present, therefore there is no contingency buffer possible for these.

Forecast elements within a TAF predicting any conditions below landing minima require 30 minutes to be added to the beginning and end of the forecast period to allow for weather starting early or finishing later than expected. TTFs do not have this requirement (as a result of the continuous weather watch provided by a TTF).[16]

Forecast validity periods and retrieval time prior to arrival

For some flights, there are fewer forecasts available at the time of planning (or in-flight) when the flight duration is relatively similar to the forecast validity period. If the duration of a flight is longer than difference between forecast validity period and the forecast release frequency, there is a chance that the forecast may not cover the planned arrival time.

For domestic flights within Australia, this chance is particularly relevant to TTFs with their 3 hour validity period. TTFs were typically released every 30 minutes for Adelaide (being attached to reported observations in METARs or SPECIs). As a result, for TTF retrievals between 2 hours 30 minutes and 3 hours prior to arrival, the validity period of the particular TTF retrieved can only be used for planning for up to 30 minutes after retrieval. For example, for a planned arrival time 2

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[15] AIP ENR 59.2.9 and ENR 59.2.11 dated 18 Aug 2016.

[16] AIP ENR 59.2.9 dated 18 Aug 2016.

hours 45 after TTF retrieval, the TTF is only valid (and therefore available) for use to plan the arrival in the 15 minutes immediately after the TTF release (after this period, the TTF is too old to use).

For a given routine forecast release frequency and validity period, there is a time period where forecasts do not cover arrival times for forecast retrieval times prior to arrival that are close to the forecast validity period. As a proportion of all time, this can be defined by the following equation:

$$Percentage\ of\ forecast\ availability = \left\{\left(1 - \frac{\Delta t_R - \Delta t_O}{t_F}\right) \times 100\right\}\ for\ \Delta t_R > \Delta t_O,$$
$$\{100\%\}\ for\ \Delta t_R \leq \Delta t_O$$
$$Where: \Delta t_R: forecast\ retrieval\ time\ prior\ to\ arrival$$
$$, t_F: routine\ forecast\ release\ frequency$$
$$, \Delta t_O: forecast\ validity\ period\ offset = \ forecast\ validity\ period - \ t_F$$

Practically, this means that for a routine forecast to be available for use 100 per cent of the time, retrieval needs to occur after the forecast validity period offset time prior to arrival. For shorter domestic flights, this limitation will typically only apply for TTFs at larger international airports. However, this also applies to TAFs for long-haul international arrivals.

Measuring the operational reliability of weather forecasts

This research investigation was designed to evaluate the aviation weather forecasting *within* the system as designed, rather than focus on the precision and accuracy of particular forecast parameters. As such, the forecast versus reported values for each parameter are evaluated in the context of them prompting particular operational decisions to be made. These are based on stipulated thresholds, such as the landing and alternate minima.

In other words, the main focus of this report is about whether weather forecasting provides sufficient warning for a flight crew to be able to be assured of a safe landing, either at the planned destination, or an alternate location.

Comparisons between forecasts and (observation) reports were performed based on combining the following forecast and reported ‘operational states’:

- Forecasts (TAFs and TTFs):
  - above the alternate minima
  - between the alternate and landing minima
  - below the landing minima
- Reported observations (METARs and SPECIs):
  - above the alternate minima
  - between the alternate and landing minima
  - below the landing minima.

Combining these forecasts and reported observation states results in nine logical comparison states, as shown in Figure 6.

Note that the groupings between the landing and alternate minima only apply for the weather parameters visibility and ceiling, as these are the only values with differences between the landing and alternate minima thresholds.

Figure 6: Forecast predictions compared to actual observations including conditions between landing and alternate minima

		Reported observation: Below landing minima	Reported observation: Between landing and alternate minima	Reported observation: Above alternate minima
Forecast	Below landing minima	3 HIT (H1)	6 PARTIAL HIT (PH)	9 FALSE ALARM (FA1)
Forecast	Between landing and alternate minima	2 SYSTEM BUFFER (B1)	5 HIT (H2)	8 FALSE ALARM (FA2)
Forecast	Above alternate minima	1 MISS (M)	4 SYSTEM BUFFER (B2)	7 CORRECT REJECTION (CR)

The following summarises each comparison state:

- MISS - Unsafe scenario.
  - 1 (M) – A flight crew receive information that indicates no contingency plan is required, however, it is not possible to land upon arrival at the destination.
- HIT - Forecast matches observed operational state
  - 3 (H1) – Forecast indicates that alternate minima planning is required (below the landing minima), and the scenario eventuates where a landing is not possible at the planned destination.
  - 5 (H2) – Contingency plan required, however, conditions are degraded but allow landing (conditions between landing and alternate minima).
- PARTIAL HIT – Applies only to degraded visibility and ceiling.
  - 6 (PH) Forecast predicts worse conditions than observed, however, conditions are degraded but allow landing.
- SYSTEM BUFFER – the difference between the alternate and landing minima has potentially influenced the outcome – a successful defence. This applies only for degraded visibility and ceiling.
  - 2 (B1) – Forecast used by the flight crew indicates that an alternate minima is required (between landing and alternate minima), and the scenario eventuates where a landing is not possible at the planned destination. This scenario indicates where the system design has accounted for a larger than expected deterioration of conditions.
  - 4 (B2) – Weather conditions forecast to be above the alternate minima, although observed to be between the alternate and landing minima. Landing would be possible and alternate minima criteria related decision making would not be required. This represents a scenario where the inherent buffer between the alternate minima and landing minima comes into effect to account for forecast inaccuracy.
- FALSE ALARM: the forecast would require alternate minima contingencies, however, no degraded conditions (below the alternate minima) were observed
  - 9 (FA1) Forecast below the landing minima, observed above the alternate minima.
  - 8 (FA2) Forecast between the landing and alternate minima, observed above the alternate minima.
- CORRECT REJECTION
  - 7 (CR) Conditions fine with no operational effect. The forecast and observations both above the alternate minima.

Key terminology

The analyses of data presented below refers to various states described above through the use of *primed* and *unprimed* as follows:

- *Unprimed observation below the landing minima*: A Miss (M1) from Figure 6. This is often referred to as just an *unprimed observation*. This is the unsafe situation where landing is not possible at the time of arrival (below the landing minima) but there was no contingency plan required from the forecast.
- *Primed observation below the landing minima*: Either of states B1 and H1 from Figure 6. That is, although landing is not possible at the time of arrival (below the landing minima), a contingency plan was required from the forecast.
- *Unprimed observation between the landing and alternate minima*: The system buffer state (B2) from Figure 6.

Methodology summary

The information below provides a high level summary of the methodology used. A detailed version of this methodology is provided in a separate report, *Methodology for determining the operational reliability of Australian aviation weather forecasts*.

Data sources

All aerodrome weather forecasts (TAFs and TTFs) used for the assessment of reliability were provided by the Bureau of Meteorology to the ATSB for Mildura and all major Class C airports between 2009 and 2013. For comparison, observation reports (METARs or SPECIs) were provided for the same locations and period of time. METAR and SPECI data were provided in a slightly higher fidelity than publically released. For Mildura alone, about 7,700 TAFs and 90,000 weather observation reports were provided for the five year period.

These data were the actual forecasts and reports released for use by pilots over this period.

Aircraft specifications were gathered from various sources, including the aircraft manufacturer's flight manuals, operator's websites, and reference books. Aircraft models were selected based on those models used by large Australian-based commercial public transport operators. (All analysis for Adelaide and Mildura were based on category D aircraft only, using a Boeing 737-800 aircraft as the exemplar.)

A complete set of instrument approach procedural charts from Airservices Australia were utilised for every aerodrome of interest in the study. These were sourced within the Departure and Approach Procedures (DAP) section of the publically available Aeronautical Information Package (AIP). Some runway and waypoint information was already held by the ATSB as provided routinely by Airservices Australia.

Civil twilight start and end times were extracted from the Geoscience Australia website.

Aircraft arrivals data were provided by Airservices Australia for every location. Data were aggregated for every hour of day (local time) from 2010 to 2013 for all requested airports.

Forecast interpretation and selection of instrument approaches (B737-800 aircraft)

For every forecast and observation used in the assessment, a series of selections were required pairing these with runways, instrument approaches, and landing and alternate minima applicable to a Boeing 737-800 aircraft. Additionally, a formalised interpretation of each forecast was required.

For every forecast and observation, the following procedures were applied to select an instrument approach procedure and subsequently landing and alternate minima. Selection of an instrument approach required two sets of metrics to be calculated as described below.

Instrument approach and minima selection metrics

Difference between instrument approach and forecast or observation minima calculated

Every instrument approach was combined with each forecast and observation for comparison. To allow the ranking of each approach and forecast/observation combination, a weighting was calculated based on the percentage difference between each minima criterion.

The following equations describe how the percentage difference (labelled 'PD') was calculated between observations/forecasts and the published aircraft limits, and alternate and landing minima thresholds, defined by the following equations, where 'Vis', 'Ceil' and 'RVR represent values of visibility, ceiling and RVR calculated separately, and 'Wind' represents values of either crosswind or tailwind, also calculated separately of one another:

$$PD_{Vis,Ceil,RVR} = \frac{F_{Vis,Ceil,RVR} - IAP_{Vis,Ceil,RVR}}{IAP_{Vis,Ceil,RVR}} \times 100, PD_{Wind} = \frac{AC_{Wind} - F_{Wind}}{AC_{Wind}} \times 100$$

The percentage difference was used for two purposes:

- Showing if the minima was breached. A negative value indicates conditions below a minima criterion.[17]
- The difference between published thresholds and respective weather forecast or observation values (the magnitude of percentage difference). Variations in these values were used to calculate a weighting for each comparison and select a single instrument approach and alternate minima.

Weighting prioritising visibility and ceiling over wind calculated

A single weighted value for every forecast/observation and landing minima combination was calculated according to the following equation:

$$Weighting = \max(PD_{RVR}, PD_{Vis}) + PD_{Ceil} + 0.1 \times (PD_{Crosswind} + PD_{Tailwind})$$

This weighting gives priority to variations in the published visibility and ceiling minima over wind conditions approaching aircraft limits, which were reduced to 10 percent of the original values. For the purpose of analysis, this only becomes relevant when there were no approach options above the landing or alternate minima, and a selection was required between accepting a less favourable wind direction over the preserving visibility minima. This was done to allow the analysis of the effect that differences between the accuracy of instrument approaches for different runways had on expected aircraft arrivals.

Note that thunderstorms were not included in the weighting due to these having no relative difference between different minima options.

Most accurate Instrument approach selected

The instrument approach procedure with the largest percentage difference between forecast/observed conditions and instrument approach minima was selected for each forecast or observation. This was performed for the purpose of assessing how close the forecast or observation conditions were to the lowest limit available for landing.

When at least one landing minima criteria was breached, the approach with the largest selection weighting (described above) was used.

Special alternate minima

Alternate minima were selected from the (already nominated) instrument approach plate mentioned above. If a special alternate minima was available for use, this was selected if it was allowed for the aircraft and forecast conditions.

Worst case forecast predictions used

In scenarios where a TAF or TTF had temporary or probabilistic components covering a common time period, the segment with the most severe forecast or observed conditions were selected. These were selected in the following order:

- forecast segments below landing minima
- forecast segments below alternate minima
- forecast – approach selection weight (described above).

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[17] The two equations for percentage difference were selected to always have a negative value when conditions were below the minima. This was required because the instrument approach procedures are based on conditions above a minimum value, and the aircraft crosswind and tailwind limitations being a maximum value.

Forecast adjustments based on Australian planning rule set

TAFs had an additional 30 minutes added to the start and end of TAF forecast segments predicting conditions below the alternate minima.

TTFs had no timing adjustments performed.

This is in accordance with the current Australian flight planning rules, and was implemented to simulate the system in its current state, and to establish a baseline for further analysis.[18]

Overview of data extraction and evaluation

From the raw data outlined in *Data sources* above, tables were constructed for individual elements of the weather forecasts and observation reports, instrument approach details, and aircraft specifications.

A relational database was developed to store all details of METAR and SPECI reports, and TAF and TTF forecasts. A number of measures were implemented to validate the data to provide confidence in the nature of the source data.

Two checks were performed to pre-exclude invalid TAF and TTF data:

1. segment start time greater than or equal to the next segment start time
2. segment start time greater than the segment end time.

Timing buffers (for simulated contingency planning) were added where required to TAFs, but not TTFs. As already noted, conditions forecast by a TAF triggering an operational contingency requirement were treated as starting and ending 30 minutes prior to and after the predicted time. Apart from the timing buffer changes mentioned, TAFs and TTFs were treated using identical techniques for forecast comparison and analysis.

Aircraft specifications were combined with the published instrument approach data within a relational data structure to determine the landing and alternate minima that would apply to the selected aircraft.

Data were removed if the aircraft performance specifications did not meet five requirements published in the instrument approach procedure, based on aircraft performance category, multi-variant design (MVD) category, ILS capability, required navigational performance (RNP), and minimum missed-approach climb gradient.

All alternate minima combinations for each runway were aligned to each aircraft model.[19] For every TAF and TTF sub-segment, the most appropriate set of alternate minima criteria were selected for each nominated aircraft, taking into account possible runways.

For each aircraft, the most appropriate instrument approach was selected for every METAR and SPECI report. Conditions suitable for landing were assessed against the requirements put forward in the AIP documentation and instrument approach procedures applicable to the conditions and aircraft.

Comparisons were made of overlapping TAF and TTF forecasts with METAR and SPECI reports. Calculations of the operational effect of a forecast throughout the validity period were then made, with validation checks of logical inconsistencies.

Finally, the simulation of the effect of nominated retrieval times prior to arrival was conducted, with the main objectives being to determine:

18 AIP ENR 59 dated 18 Aug 2016.

19 Adelaide and Mildura analyses were based on category D aircraft only (using a Boeing 737-800 aircraft).

- The likelihood of retrieving a forecast predicting favourable conditions, when the conditions at the time of arrival are reported as below safe landing limits.
- The potential impact that this may have on aircraft using estimates of the potential aircraft unexpected holding time, and the expected number of aircraft arrivals during those times.

Comparisons between forecasts and observation reports

Forecast conditions below the alternate minima were assumed to impose an operational contingency requirement, and observed conditions below the landing minima were assumed to be the limit of an aircraft to conduct a safe landing.

The comparison of these two states was performed to indicate the potential operational effect of planning based on the alternate minima state of the forecast, and the resultant reported conditions affecting the ability to land. This measure is intended to provide an indication of the effectiveness of the forecasting safety system by taking account of the buffer between the alternate and landing minima.

For example, if conditions were forecast below the alternate minima, it is expected that a contingency plan would be able to be implemented by a flight crew, such as taking on additional holding fuel or planning for an alternate aerodrome. If on arrival, conditions were reported below the landing minima, this comparison would be recorded as a 'hit' according to Figure 7.

The four states outlined in Figure 7 focus on the operational effect to aircraft, are the condensed version of the nine states shown in Figure 6. The condensed states were used in the algorithm to rank forecasts and observations by operational effect, however, the nine-state comparison is used when required in the analysis. With reference to Figure 6 on page 26, the nine-state comparison is condensed to four by combining *forecast between* landing and alternate minima with *forecast below* landing minima, and *observations between* landing and alternate minima with *observations above* the alternate minima.

Note that if conditions were reported above the landing minima (even if below the alternate minima), it would be recorded as a 'false alarm' for this comparison. In contrast, if forecast conditions were above the alternate minima and reported conditions were below the landing minima, this was recorded as a 'miss'. Forecast conditions above the alternate minima and reported conditions above the landing minima were recorded as a 'correct rejection', even for reported conditions between the landing and alternate minima states. In both cases, these states are divided for the purpose of analysis.

Figure 7: Forecast predictions compared to reported observations

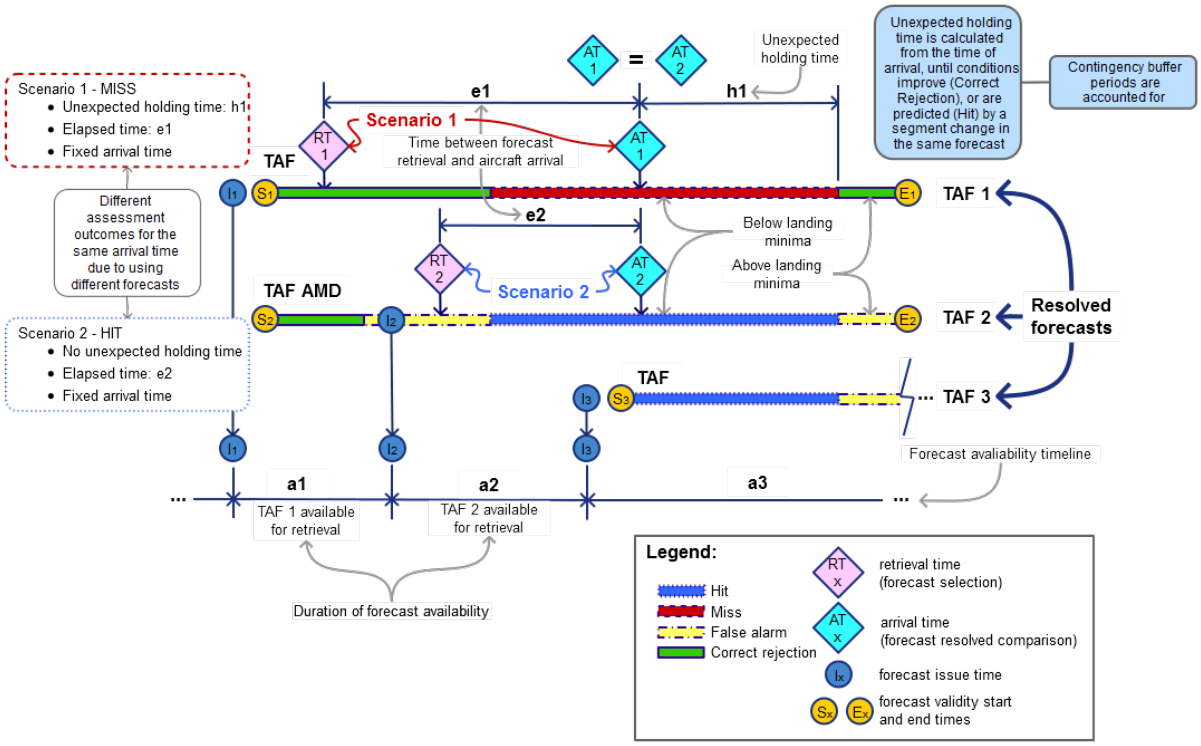
		Report (METAR/SPECI) YES	Report (METAR/SPECI) NO
Prediction (TAF or TTF)	**YES**	**1** (Hit)	**3** (False alarm)
	NO	**2** (Miss)	**4** (Correct rejection)

Forecast reliability

For weather related operational decision-making, it was considered important to understand the effects of varying forecast retrieval times prior to arrival. This is because operational effects may differ depending on the time of forecast retrieval, leading to different operational decisions, such as carrying additional fuel, or diverting.

Figure 8 shows how different operational results are possible for arrival at the same time (light blue diamonds labelled 'AT 1' and 'AT 2') when using separate, overlapping forecasts (TAF 1 and TAF 2).[20] The two scenarios presented show forecast retrievals at different times (pink diamonds labelled 'RT 1' and 'RT 2'), and different elapsed times from retrieval prior to arrival (labelled 'e1' and 'e2').

Figure 8: Measuring operational effect of individual forecasts following retrieval at different times prior to arrival at the same time



Forecast availability

In scenario 1 (S_1 in Figure 8), a 'miss' is recorded at arrival time 'AT 1' because at the time of forecast retrieval (RT 1), forecast 'TAF 1' was available. This is due to the retrieval time 'RT 1' falling between the 'TAF 1' issue time (blue circle labelled 'I_1'), and the 'TAF 2' issue time (blue circle labelled 'I_2'). This duration in time, labelled 'a1' refers to the availability of the forecast.

Conversely, for scenario 2 (S_2 in Figure 8), a 'hit' was recorded at the same arrival time because the forecast was retrieval (RT 2) when the amended TAF, 'TAF 2' was available. The duration of availability of TAF 2, labelled 'a2', spans between the TAF 2 and TAF 3 issue times ('I_2' and 'I_3').

The forecast availability is important when considering out of sequence forecast releases such as amended TAFs. Consider TAF 2, which covers the same validity period and amends TAF 1. The likelihood of a flight crew retrieving and using the information contained in TAF 1 is expected to be proportional to the availability period labelled 'a1'.

If the period between the issue of two forecasts is short, the likelihood of the retrieval of the earlier forecast also diminishes, and conversely, if the period between forecast issues is longer, a relative increase in the likelihood of retrieval of the earlier forecast is expected.

Unexpected holding time

A potential unexpected holding time labelled 'h1' applies to scenario 1. This is based on the expectation that a flight crew would be unprepared to hold if their decision making and planning

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[20] Note that the same process is applied for TTFs.

was basing around TAF 1, which predicted conditions above the alternate minima, however, on arrival, conditions were reported as unsuitable for landing (below the landing minima). The calculated holding time starts at the time of arrival and ceases effect after duration ‘h1’ when either conditions improve (which applies in this case), or a forecast segment in the same forecast would be expected to trigger contingency planning (conditions forecast below the alternate minima).

No unexpected holding time applies to TAF 2 as it is expected that the crew would be reasonably warned that a contingency plan was required.

Forecast timelines for fixed retrieval times prior to arrival

To gain a holistic understanding of operational reliability of forecasting, the historical availability of particular forecasting attributes were analysed, such as the expected number of ‘misses’ over a period of a day or month, or over all data available.

The likelihood of a forecast being retrieved was expected to be related to the duration of forecast availability described above, the number of aircraft arrivals at given times, and the times prior to arrival that flight crew or other operations personnel are likely to retrieve these forecasts.

The time a particular comparison scenario existed can be used to indicate the chances of exposure to particular conditions if an aircraft were to arrive at a particular time of day or month. Multiple timelines were produced in 15 minute retrieval time offsets, allowing the assessment of the relative likelihood of forecast reliability as the simulated retrieval time prior to arrival increased.

Each of these simulations were independent of one another, with the total duration of each timeline adding to the same number. Observations remain unchanged, with the simulation acting to select and interpret different forecast outcomes based on the retrieval time prior to arrival and the forecast interpretation scenario.

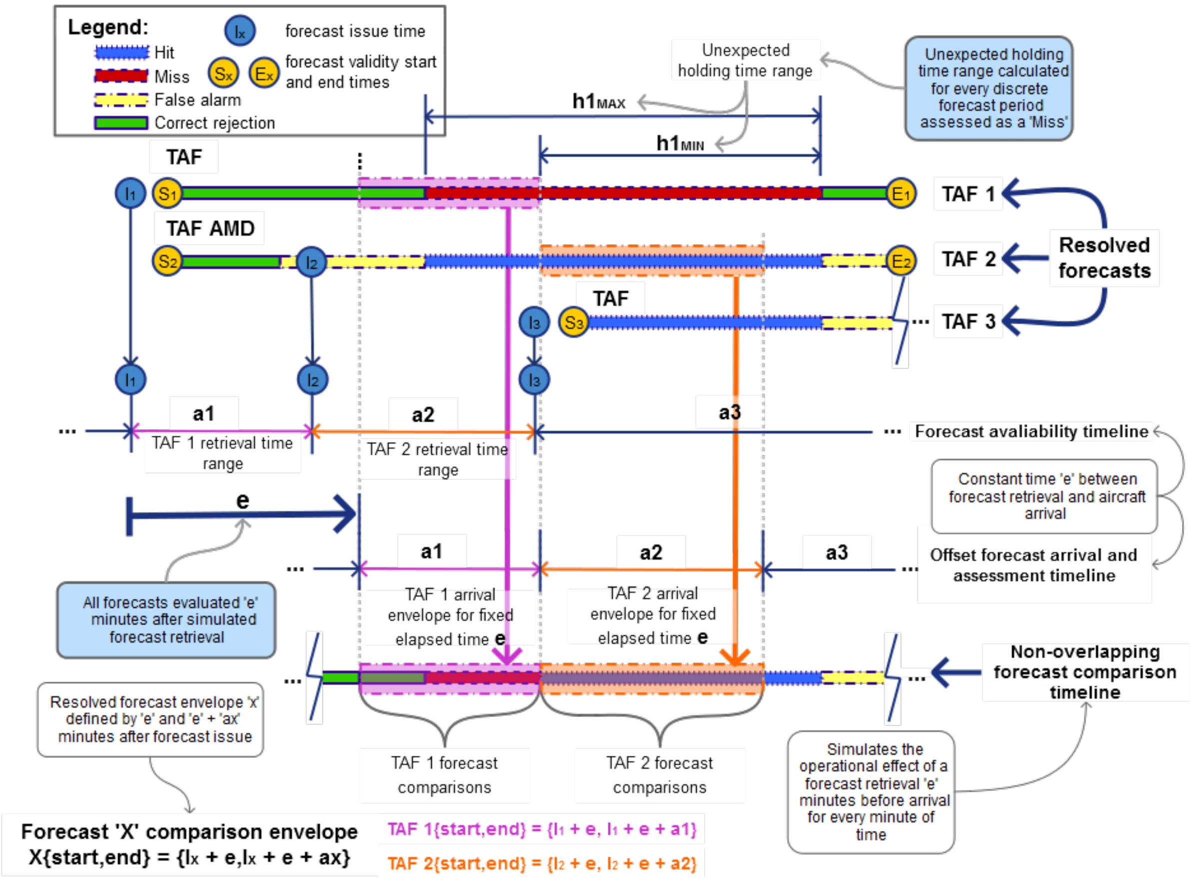
Calculating the availability of forecast comparison states

While Figure 8 showed the characteristics of forecasting, it did not provide an indication of how likely a scenario like this would arise. Since forecasts are only available for discrete periods of time (the forecast availability discussed above), this represents the maximum envelope of time that the forecast could be retrieved.

For example, if a forecast was available for retrieval for 24 hours in one year, the odds of randomly selecting this forecast in one year would be approximately 1 in 365 days. Of course, the actual retrieval of forecasts is not expected to be random, which is accounted for in part by approximating the number of aircraft affected, discussed on page 36.

Figure 9 shows the process of creating a single timeline, simulating the effect of retrieving the available forecast (shown in Figure 8) for every minute of time at a given location, and recording the forecast-report comparison for that forecast at a constant time, labelled ‘e’, after forecast retrieval. For reference, Figure 9 refers to the same fictitious data as Figure 8.

Figure 9: Creating a non-overlapping forecast comparison timeline to assess operational effect of all forecast retrievals at the same time offset prior to arrival



In this case, rather than having a single retrieval time point, as in Figure 8, a retrieval time *range* exists for each forecast, corresponding to the forecast availability. If the start and end times of the time range are shifted by the elapsed time 'e', an aircraft arrival time envelope can be calculated for every forecast.

The forecast comparison data within this resultant time range is then inserted into the 'non-overlapping forecast comparison timeline', as labelled. For example, the assessment state on arrival TAF 1 started as a 'correct rejection', followed by a period assessed as a 'miss'.

To illustrate this further, Table 2 contains sample calculations based on Figure 9, with a simulated constant retrieval time prior to arrival set at 90 minutes.

Using TAF 1 as an example, it can be seen that the availability, or retrieval time range, is recorded between the issue of TAF 1 at 0540, and the issue of TAF 2 at 0705. This means that if a request for the current forecast was submitted during this time, the forecast TAF 1 would be retrieved. The time difference of 85 minutes corresponds to 'a1' in Figure 9.

The arrival envelope is calculated by shifting the availability period start and end times by 90 minutes from 0540 to 0710, and 0705 to 0835 respectively. This new arrival envelope corresponds to the only period in time that TAF 1 can have operational effect given a fixed 90 minute period between retrieval and arrival. In the case of TAF 1, a forecast retrieval in the first 30 minutes of availability would result in arrival during a 'correct rejection'. Subsequently, for a constant 90 minute retrieval time offset, the availability of the forecast comparison state 'miss' was 55 minutes for TAF 1.

Table 2: Sample calculations from Figure 9 of assessment states and holding time for simulated forecast retrievals 90 minutes prior to arrival

Retrieval time prior to arrival (e) (minutes)	Forecast label	Issue time	TAF comparison start time	TAF comparison end time	Forecast retrieval availability period (a)	Holding duration		Availability by comparison states at arrival 90 minutes after forecast retrieval				
						h_{MIN}	h_{MAX}	Hit	Miss	False alarm	Correct rejection	Total
90	TAF 1	0540	0710	0835	85	135	190	0	55	0	30	85
	TAF 2	0705	0835	1030	115	0	0	115	0	0	0	115
	TAF 3	0900	1030	N/A	N/A	0	0	20	0	35	0	N/A

The formation of non-overlapping forecast comparison timelines enabled an overall analysis of the systemic performance of all forecasts of the same type at a location. For example, for the displayed period in Figure 9 and Table 2, the availability for arrival during conditions reported below the landing minima (recorded as a 'hit' or a 'miss') can be directly calculated from the timeline, in this case 55 (TAF 1) + 115 (TAF 2) + 20 (TAF 3) = 190 minutes.

Note that the availability of a forecast comparison state was not used to indicate the potential impact on aircraft safety. For example, the availability of the TAF 1 'miss' state is less than the overall assessed misses for TAF 1 because the amended forecast TAF 2 was released. For potential impact on aviation safety, an estimated holding time *range* was calculated.

Unexpected holding time range

The concept of unexpected holding time for a single time of arrival was introduced in Figure 8, as the time starting at the arrival during a forecast 'miss', until conditions below landing minima ceased or the forecast comparisons changed to a 'hit'. Due to a timeline being produced (as opposed to a single arrival time), a *range* of holding times exist for every 'miss'. These range from arrival at the start of the 'miss' up until the end, as shown in Figure 9. The minimum and maximum calculated holding times are used to provide an indication of the overall time an aircraft would be required to hold in the air.

Table 2 columns labelled 'h_{MIN}' and 'h_{MAX}' show values for calculated minimum and maximum holding times for TAF 1. This represents the shortest and longest durations of time that an aircraft would have to hold after retrieving TAF 1 at the start and end of the TAF 1 'miss' availability, as shown in the non-overlapping forecast comparison timeline of Figure 9. The minimum holding time corresponds to arriving at the end of the 'miss' period, where conditions were predicted to degrade, or were reported to improve. Accordingly, the maximum holding time corresponds to arrival at the start of the 'miss' period. Note the difference between the maximum and minimum holding times corresponds to the total availability of the 'miss', in this case 55 minutes.

Note that multiple discrete periods of ‘misses’ either between forecasts or within forecasts (due to gaps between forecast ‘misses’) existed for some periods, which were calculated separately in each case. For the purposes of analysis, an additional ‘average’ holding time was calculated in each case. For example, this would equate to 163 minutes for TAF 1 of Figure 9 and Table 2.[21]

Calculation of expected aircraft arrivals

Calculating the availability of a forecast shows the times that a forecast would take effect given constant forecast retrieval prior to arrival times, as described in *Forecast availability* on page 32. To indicate the potential effect this has had on actual flights, availability data were combined with an aircraft arrivals data model to estimate the number of aircraft arriving during each forecast comparison state after a simulated forecast retrieval.

The main three steps involved this process involved are:

- Development of expected aircraft arrivals model
- Forming hourly splits in non-overlapping forecast comparison timelines
- Calculating expected aircraft arrivals for forecast comparison ‘states’.

It is important to note that in these calculations, the total number of simulated arrivals remained the same as the actual number of arrivals in every simulation. It is the distribution of those numbers that change based on each forecast retrieval simulation.

Development of expected aircraft arrivals model

It was expected that during periods where conditions were reported below the landing minima, aircraft arrivals would cease, or be significantly reduced during that period. To account for this, a model of aircraft arrivals was produced using Airservices Australia flight activity data provided to the ATSB on an hour by hour basis, allowing relatively high fidelity to calculate the total effect weather forecasting has on aircraft operations.

The objective of the model was to estimate the number of aircraft that *would* have arrived at a given time, had the weather been suitable for landing.

The algorithm developed allowed for different models of expected aircraft arrivals, however, the arrivals data averaged in groups of the hour of day, weekend or weekday, and month. This data were then normalised by yearly arrivals, ensuring that the total expected arrivals in the model matched the total yearly arrivals.[22]

An example of an average group is the total of all aircraft arrivals at 1000, on weekend days in June, a total of about eight data points per year. The average of this group corresponds to the number of expected arrivals per hour for each group.

A simple concept of this model is shown in Figure 10 (top portion) with peak arrivals shown as three arrivals per hour between 0900 and 1000, tapering by one aircraft per hour in the surrounding hours.

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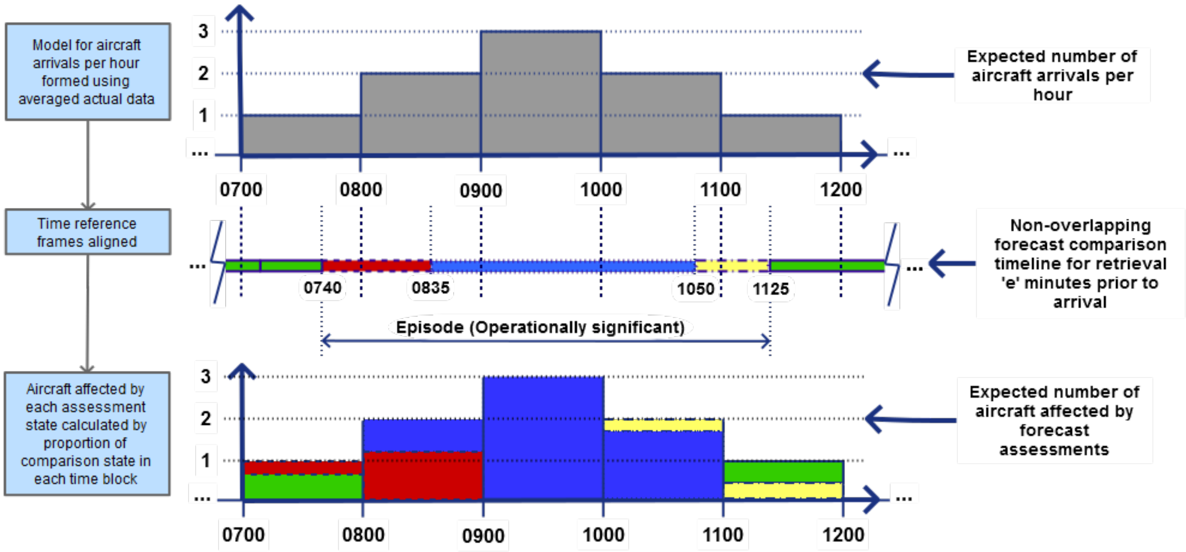
[21] This is the average of the minimum and maximum holding time – in this case for TAF1 in Table 2 (135+190)/2 = 162.5 minutes.

[22] The aircraft flight activity data were grouped to a level that it was expected that flight arrivals would be similar. This data is expected to be conservative, as natural reductions in traffic movements due to poor weather – flight cancellations – will result in less aircraft being calculated as part of the total than those actually affected.

Figure 10: Calculating the number of expected aircraft arrivals by different assessment states in each non-overlapping forecast comparison timeline (as shown in Figure 9)



Forming hourly splits in non-overlapping forecast comparison timelines

Each non-overlapping forecast comparison timeline was adapted to summarise data by local time in hourly groups. This included the representation of unexpected holding time ranges and the availability to assessment states as shown in Figure 9.

Table 3 shows the results of this reclassification from that shown in Table 2. Note that this process no longer specifically references any forecasts, although the holding time is still calculated using specific forecast-report comparisons. For example, the estimated holding time still has a maximum recorded as 190 minutes, which reduces down to a minimum of 135 minutes, as shown in Table 2. However, additional divisions are made reflecting the 0800 split of 20 minutes into the availability period of the 'miss'. If more than one holding period existed within an hour, the average of each of the minimum and maximum values were used.

Availability periods were calculated by adding the time of each assessment state within each hour.

Calculating expected aircraft arrivals for forecast comparison 'states'

The model of expected aircraft arrivals per hour was multiplied by the hourly proportion of each forecast comparison state in the same hour grouping according to the following equation:

Aircraft affected = Hours of availability to assessment state × Expected aircraft arrivals per hour

Expected aircraft arrivals are expressed as a decimal rather than a whole number due to the averaging process used to determine the expected aircraft arrivals and the fractions of an hour that availability of comparison states occur (as the smallest unit of measurement in the analysis is one minute).

Once the number of aircraft arrivals by hour was determined, these figures were then aggregated as required. All expected aircraft arrivals calculations were performed at an hour by hour level throughout the study period. The results dataset also included sunrise and sunset data to allow analysis relative to these times. Local time is presented to show alignment with forecast releases and flight schedules.

Table 3 shows the expected aircraft arrivals for the data shown in Figure 10. For example, between 0900 and 1000, only a hit is recorded as available, therefore, this is calculated as 1.0 hour availability x 3 aircraft per hour = 3 aircraft. Another example is the calculation of a 'miss' between 0700 and 0800 where 20/60 hours availability x 1 aircraft per hour = 0.33 expected aircraft arrivals.

Table 3: Sample summary of operationally significant episode (shown in Figure 10) including expected aircraft arrivals, availability of assessment states, and estimated aircraft holding time by hour of day for a simulated forecast retrieval 90 minutes prior to arrival (shown in Table 2)

Hour of day	Estimated aircraft holding time (minutes)		Availability to assessment state (minutes)				Expected aircraft arrivals			
	h_{MIN}	h_{MAX}	Hit	Miss	False alarm	Correct rejection	Hit	Miss	False alarm	Correct rejection
0700	170	190	0	20	0	40	0	0.33	0	0.67
0800	170	135	25	35	0	0	0.83	1.17	0	0
0900	0	0	60	0	0	0	3	0	0	0
1000	0	0	50	0	10	0	1.67	0	0.33	0
1100	0	0	0	0	25	35	0	0	0.42	0.58
Total	N/A	N/A	135	55	35	75	5.5	1.5	0.75	1.25

Grouped episodes

To evaluate periods with forecast below the alternate minima or reported conditions below the landing minima, an algorithm was developed to group non-overlapping forecast comparisons. Conditions were considered as falling within the same episode if the comparison state improved to a 'correct rejection' but returned to any other comparison state (as shown in Figure 6) within one hour.

Identification and validation of critical records

Extensive processes were developed to check a number of key fields used in the analysis – specifically fields relating to the calculation of visibility, cloud base (ceiling) and various timing fields.

Approximation of visibility and ceiling values

Reported visibility and ceiling information was critical to the overall analysis of forecast reliability. This was due to these being the main elements used in published navigation thresholds to determine if the landing or alternate minima are breached at an aerodrome.

In cases where no explicit cloud or visibility information was contained in the observation report, a number of other information sources were used in lieu. In cases where these values could not be identified or approximated, these records were excluded and assumed safe conditions for the purposes of the analysis. A breakdown of these classifications are shown in Table 9, Table 10 and Table 11 on pages 159 - 160.

Validation of time fields

During the process of extraction of data, all time based fields were assessed for completeness prior to their use in analysis.

Following the process of creating a single timeline for each forecast, the timing data were summarised and checked for inconsistencies. The validation focused on forecast time duration as this was a critical component of this analysis, being the numerator for the majority of results and conclusions in analyses.

Validation checks performed on the data set were:

- check-sums comparing the original decoded forecast validity period with the resolved comparison segments

- the assessment of duplicate or simultaneously released reports
- identification of longer than typical duration between released reports
- holistic simulation time vector check-sums.

Records identified as invalid were flagged for removal for each forecast-observation report comparison. To ensure that valid records surrounding these were evaluated fairly, the relevant times that these segments would have been active were used in the analysis with no assessment, and were recorded as 'Not decoded' (shown in Figure 18 on page 55 and Figure 63 on page 110).

Data limitations

Aerodrome meteorological reports (METARs and SPECIs)

To measure the relative accuracy of aerodrome (TAF) and trend (TTF) forecasts, aerodrome reports (METARs and SPECIs) were used to represent the 'real-world' conditions at the time of predictions.

Conditions are assumed to be those reported by the last report released, until the time that the next report is released, up to a maximum time gap of 60 minutes (although the vast majority of reports are released within 30 minutes of one another for most reports of interest in this study).[23] As such, any slight fluctuations in conditions are not taken into account, unless a new report is released.

However, during periods of adverse weather to aviation, such as during high winds, thunderstorms, low cloud or low visibility, criteria are applied which stipulate an immediate report release if any of a number of changes are observed.[24,25] Therefore, for adverse weather periods, and periods of change, it is expected that conditions can be adequately represented, due to any significant fluctuations requiring a new report to be released.

Artificial time delay for reports following deteriorated weather conditions

Australian documentation states that a 10 minute delay is applied to the release of SPECIs following an improvement of visibility, weather or cloud to METAR conditions[26]. However, for improving conditions below the SPECI threshold, it was less certain how these were reported at Australian aerodrome weather stations.

An analysis was conducted reviewing observations released within 20 minutes of one another to understand if this time delay would apply to improving conditions from below the landing minima. This is covered in *Appendix B – Releases of SPECIs following conditions below the landing minima* on page 154.

As a result of this analysis, it was concluded that this would not significantly affect the analysis for the purpose of measuring the duration of conditions below the landing minima.

Hourly aircraft arrivals used to estimate aircraft affected by weather

The hourly aircraft arrivals model used in this analysis produces an expected number of arrivals at a given time of day throughout the duration of the Adelaide and Mildura analyses. This model is intended to estimate the number of aircraft arrivals at a given time throughout the five-years of analysis. This includes periods of weather reported below the landing minima, and is discussed further in *Calculation of expected aircraft arrivals* on page 36.

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23 See *General release timing characteristics of METARs and SPECIs* on page 153.

24 AIP GEN 1.7 dated 24 Nov 2005 and AIP Supplement H24/17 dated 02 Feb 2017 *Differences from ICAO standards, recommended practises and procedures*, Airservices Australia

25 ICAO Annex 3 Appendix 4.

26 *METAR/SPECI Brochure* - 11 February 2016 – Aviation Services Knowledge Centre, Australian Government Bureau of Meteorology.

Conclusions for Adelaide Airport analysis

- An average of 17 weather episodes per year were identified with conditions below the landing minima at Adelaide Airport, an average of one episode every 22 days, equating to only 0.23 per cent of the time. Approximately 115 aircraft per year were expected to have planned arrivals during observations below the landing minima.
- Thunderstorms, rain and fog were the most common weather phenomena at Adelaide when conditions were unsuitable for landing.
  - Weather episodes involving low cloud (conditions below the landing ceiling limits) had the longest duration when compared with other landing minima.
  - Thunderstorms were the most common mechanism for conditions below the landing minima, being reported in more than half of these weather episodes.
- About eight aircraft per year were expected to arrive at times where using the only runway within visibility and ceiling limits would require a downwind landing of 10 knots or more.
- *Unprimed* observations below the landing minima (when conditions were forecast above the alternate minima) were very rare for both TAFs and TTFs (0.03% and 0.05% of the time respectively).
  - TAFs were more conservative when compared with TTFs as indicated by a lower likelihood of unprimed observations and a higher likelihood of false alarms (6.6% TAF, 5.0% TTF).
  - Considering only conditions observed below the landing minima, 1 in every 7.7 minutes of active TAFs and 1 in every 4.3 minutes of active TTFs predicted conditions above the alternate minima.
  - These occurred once in every 55 days for TAFs and once in every 38 days for TTFs on average.
  - In all but two of the 56 individual unprimed episodes for simulated TAF or TTF retrievals 2 hours prior to arrival, TTFs had the same or longer (24 episodes) duration of unprimed observations when compared to TAFs.
  - Fifteen aircraft per year if using a TAF would be expected to arrive at Adelaide during an unprimed observation below the landing minima, for averaged simulations of retrievals 0 to 2 hours prior to arrival.
  - Twenty-seven aircraft per year if using a TTF would be expected to arrive at Adelaide during an unprimed observation below the landing minima, for averaged simulations of retrievals 0 to 2 hours prior to arrival.
  - Thunderstorms and rain were expected to have the most expected aircraft arrivals during unprimed observations (TAFs - 10 aircraft per year TAFs, TTFs - 15 aircraft per year), followed by fog / mist / low cloud (TAFs – 4 aircraft per year, TTFs – 11 aircraft per year).
- Fog / mist / low cloud had the largest difference in unprimed TAFs and TTFs.
- False alarms were expected to create the largest operational differences between forecast types (TAFs or TTFs) for flight crews when solely using one forecast type over the other.
  - A difference of around 773 more aircraft arrivals per year were expected with false alarms for the scenario that all TAFs were used instead of TTFs (following the stipulated rule sets for each forecast[27]).

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27 TAFs have associated 30 minute timing buffers added to any prediction below the alternate minima, as covered in *Stipulated contingency plans* on page 21.

- Between 1000 and 1200, the largest number of aircraft arrivals during unprimed observations was expected for both TAFs and TTFs, with other elevated periods observed from 0800 to 1200 and 1400 to 2200.
- For TAFs and TTFs, elevated periods of expected aircraft arrivals during unprimed observations were in mornings in June, and between 2100 and 2200 in November.
- Unprimed fog, mist and low cloud in August, June and May had the largest differences between unprimed TAFs and TTFs compared to other months. June was also the least reliable time for predicting thunderstorms for both TAFs and TTFs.
- The largest percentage of unprimed TTFs were between 0400 and 0600, and 1000 to 1200, when compared with all observations below landing minima during these hours. These periods occurred on either side of the main weather peak period for Adelaide, corresponding to the main period of fog, mist and low cloud, over a baseline of thunderstorms.
- Based on the increased likelihood of unprimed observations below the landing minima, it is most important during the morning and early hours' quadrants for pilots to retrieve a forecast as close as possible to their arrival into Adelaide. In the morning, an increase of 2.3 aircraft arrivals per year are expected for every additional hour prior to arrival that a TAF is retrieved.
- Most unprimed episodes had estimated unexpected holding times less than 30 minutes for both TAFs and TTFs. However, throughout the day, particularly in the morning, there have been weather episodes when the estimated holding was longer than standard fuel reserves of arriving aircraft (usually between 20 and 45 minutes[28]).
  - Unexpected holding times of more than 30 minutes were predicted for a number of quadrants of day. Notably:
    - In the morning, 53 per cent of the observations following TTF retrievals and 36 per cent of simulated unprimed TAFs.
    - In the early hours, 27 per cent of unprimed observations following TTFs retrievals and 15 per cent of for TAFs.
- Using forecast conditions between the landing and alternate minima for operational decision making instead of conditions above the alternate minima considerably increases chances of arriving during unprimed observations below the landing minima.
- The systemic reaction time following unanticipated observations below the landing minima were assessed for TAFs and TTFs. For TAFs, these scenarios generally the released of an amended TAF.
  - In just over 3 episodes per year primed TAFs were released prior to the first observation below landing minima.
  - For episodes starting with an unprimed TAF, the median reaction time to recover was 35 minutes (2 episodes per year).
  - Most TTFs recovering a previous unprimed TTF were released as part of the SPECI reporting the first conditions below the landing minima in an episode (4.4 episodes per year)
- The alternate minima criteria for visibility and ceiling appear to be positioned at relatively stable values, with only slight benefit or loss from small perturbations.

[28] An additional variable reserve of up to 15 per cent applies to some aircraft – see Civil Aviation Advisory Publication CAAP 234-1, *Guidelines for aircraft fuel requirements*, for details.

Overview of weather affecting aviation at Adelaide Airport

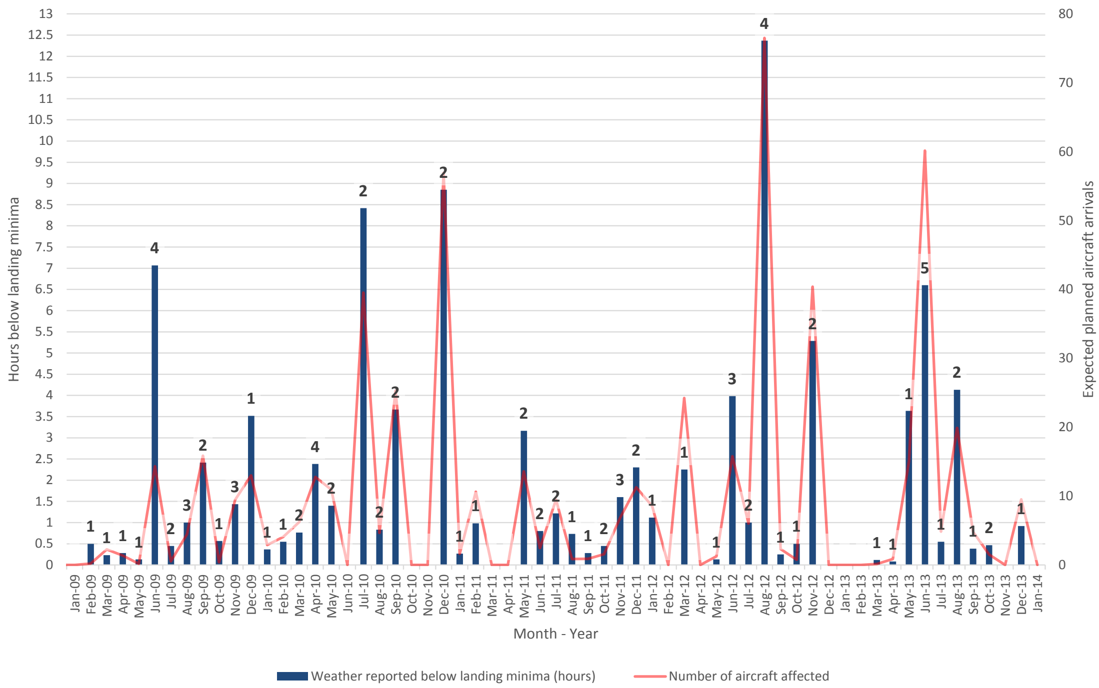
Eighty-six discrete episodes below landing minima[29] were identified at Adelaide Airport between 2009 and 2013, an average of one episode every 22 days. These ranged in duration from a couple of minutes through to more than eight hours. Half of these episodes had conditions reported below the landing minima for 30 minutes or more.

Approximately 115 aircraft per year were expected[30] to arrive at Adelaide during periods below the landing minima between 2009 and 2013. These are shown by month as the red line in Figure 11.

The figure also shows the total hours in each month where conditions were reported below the landing minima (blue columns). The numbers at the top of each bar indicate the number of discrete weather episodes below the landing minima identified for each month.

Note the relative differences between the numbers of aircraft arrivals expected, and the time observed below the landing minima. When the expected number of aircraft arrivals is relatively low with higher hours below the landing minima, this indicates that more weather occurred outside peak traffic times. Conversely, if more aircraft are expected to arrive during a relatively shorter period below landing minima, this reflects weather during more common air traffic arrival times.

Figure 11: Expected aircraft arrivals, duration and number of weather episodes below the landing minima at Adelaide Airport 2009 to 2013



August 2012 had the longest reported duration below the landing minima (more than 12 hours), occurring over four weather episodes. Based on the aircraft arrivals model, approximately 76 aircraft arrivals were expected during this time.

Sixty planned aircraft arrivals were expected in June 2013 when they would have been unable to land. Behind August 2012, this was the highest number of aircraft arrivals expected, despite

29 Based on the limits of a Boeing 737-800 aircraft.

30 Based on aircraft arrival patterns.

having less time observed below the landing minima (around 6 and a half hours) than other periods (June 2009, July 2010 and December 2010). This is because the conditions below landing minima aligned with typical aircraft traffic arrivals.

In contrast, although there were four weather episodes with conditions below the landing minima in June 2009 making up over seven hours, only 14 aircraft were expected to arrive during this time.

The weather episode with the longest duration below the landing minima at Adelaide Airport between 2009 and 2013 occurred on 7 December 2010, lasting for almost 8 and three-quarter hours, and was associated with thunderstorm activity. Based on the model developed, around 56 planned aircraft arrivals were expected during the time that conditions were unsuitable for landing.

A list of the top 10 (out of 86) weather episodes expected to have prevented the largest number of aircraft from landing in Adelaide at the planned time from 2009 to 2013 are shown in Table 4. Thunderstorms, fog, low cloud, mist, rain and drizzle were the most common weather descriptors and phenomena associated with unsuitable conditions for landing at Adelaide Airport.

The most precise instrument approach at Adelaide Airport is the instrument landing system (ILS) approach on runway 23. This approach allows suitably equipped aircraft to fly considerably lower, in lower visibility than any other published approach procedure and runway direction. In some circumstances, visibility or cloud base is low and the winds favour runways with less precise instrument approaches (i.e. not runway 23), (such as on 03-04 August 2012 and 03 September 2010 shown in Table 4). In these cases flight crews may be faced with less precise approach or accepting a tailwind landing.[31]

Another notable episode was associated with low cloud and fog partially covering the aerodrome on 18 June 2013. Although the duration of this episode was sixth in descending order of magnitude, it accounted for the third highest number of aircraft expected to arrive. This was due to the weather coinciding with morning peak aircraft arrival times. This weather episode contributed to a serious safety incident. Two aircraft en route diverted to Mildura, and also encountered conditions below the landing minima at that location. This was the subject of ATSB investigation AO-2013-100. [32]

[31] The threshold selected for a tailwind was 10 knots, which is higher than the 5 knots used in other documentation as the threshold for a downwind landing (*YPAD Air Traffic Operations Version 3.0*, Australian Government Bureau of Meteorology, 24 December 2015). This was nominated to be conservative (providing an underestimate) in identifying periods of higher risk to safety.

[32] http://www.atsb.gov.au/publications/investigation_reports/2013/aair/ao-2013-100/

Table 4: Top 10 weather episodes by expected number of aircraft arrivals during reported conditions below the landing minima – Adelaide Airport 2009 to 2013

Date	Start time	End time	Hours below landing minima	Expected aircraft arrivals	Reported weather phenomena	Landing minima	Rank by weather duration
07-Dec-10	1330	0200	8.73	55.7	Rain	Thunderstorms	1
03-Aug-12	0500	1118	6.3	46.4	Fog and mist	Low cloud and visibility with strong winds affecting lowest possible instrument approach	3
18-Jun-13	0745	1200	4.25	42.4	Partial fog	Low cloud and visibility	6
19-Jul-10	0008	1013	8.08	37.1	Patches of rain, fog and mist	Low cloud and visibility	2
05-Nov-12	1600	2230	3.73	31.7	Rain	Thunderstorms	8
03-Sep-10	1034	0830	3	24.7	Drizzle and rain	Thunderstorms and tailwind or low visibility	11
14-Mar-12	0212M	1921	2.25	24.2	Rain	Thunderstorms	14
04-Aug-12	0530	1055	4.48	23.3	Fog and mist	Low cloud and visibility with strong winds affecting lowest possible instrument approach	5
10-Aug-13	0600	1000	4	19.3	Patches / partial fog and mist	Low cloud	7
21-Sep-09	1158	1556	2.08	15.1	Rain	Thunderstorms	15

Typical reasons for conditions below minima

Observed landing minima criteria

Figure 12 shows the duration and number of episodes for each landing minima as a percentage of the total time unsuitable for landing. Thunderstorms, followed by low cloud and low visibility were most frequently observed at Adelaide Airport. More than half of all episodes involved thunderstorms activity (shown as the pink columns in Figure 12).

The fourteen episodes involving tailwind were situations involving winds exceeding 10 knots favouring a runway with less precise instrument approaches (discussed above). In these cases, landing with all five landing minima intact is not possible, with either tailwind, visibility and/or ceiling being below the landing minima. It shows where the differences between instrument approach precision was expected to have an operational effect.

Compared to the number of episodes (pink columns), low cloud (ceiling) had a considerably longer duration, indicating that these episodes are longer compared with others, and is shown in Figure 13.

Figure 12: Weather criterion percentage of total episodes and time below landing minima for Adelaide Airport 2009 to 2013[33]

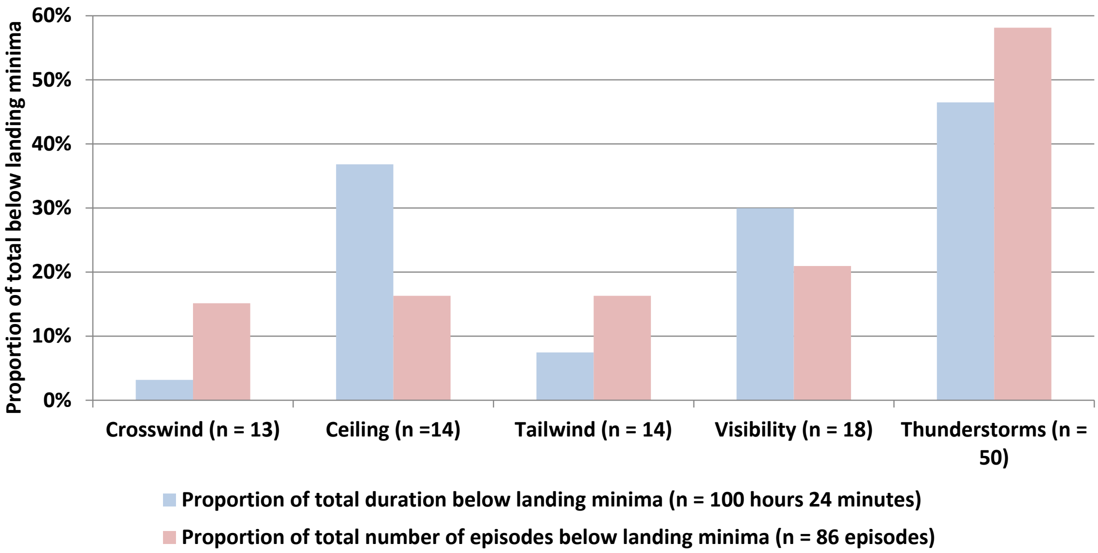
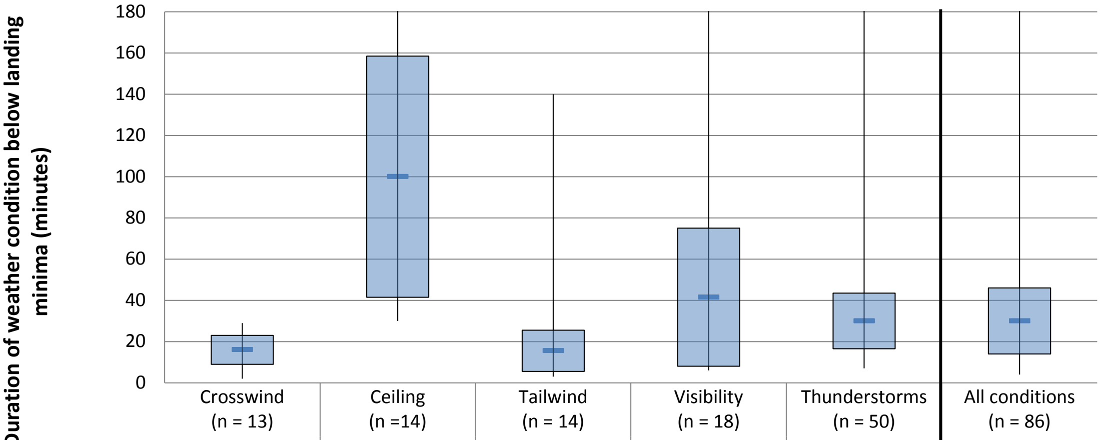


Figure 13 shows the typical duration of observed weather parameters within weather events when conditions were unsuitable for landing at Adelaide Airport between 2009 and 2013.

[33] Proportions sum to greater than 100 per cent due to more than half of all events containing more than one type of weather parameter below the landing minima.

Figure 13: Typical duration of individual observed weather parameters below the landing minima at Adelaide Airport 2009 to 2013. Blue lines show medians, columns show typical variability



	Crosswind (n = 13)	Ceiling (n =14)	Tailwind (n = 14)	Visibility (n = 18)	Thunderstorms (n = 50)	All conditions (n = 86)
Median	16	100	15.5	41.5	30	30
Median - 1 MAD	9	41.5	5.5	8	16.5	14
Maximum	29	463	140	429	524	524
Minimum	2	30	3	6	7	4
Median +1 MAD	23	158.5	25.5	75	43.5	46

The 'all conditions' bar in the right column of Figure 13 shows the typical duration of weather episodes. It displays a median time of 30 minutes. Durations below the landing minima greater than 30 minutes are expected to disrupt aircraft operations. The column shows typical variability around the median based on ± 1 median absolute deviation (MAD).[34] Conditions were reported for as little time as 4 minutes up to a maximum duration of 8 hours 44 minutes for *any* weather parameter below the landing minima (including combinations) (shown by the bars).

Thunderstorms were the most frequent factor attributed to unsuitable landing conditions, occurring in 50 out of the 86 episodes and 46 per cent of the time below landing minima (shown in Figure 12). Half of all episodes with thunderstorms typically lasted for 30 minutes or more in duration.

Although fewer episodes involved low cloud, when considered in isolation, these episodes typically endured for longer periods than any other landing minima parameter, with half of episodes lasting for more than 1 hour and 40 minutes below the landing minima ceiling. The duration of low cloud in these events also had the largest variability when compared with the other parameters.

Combinations of landing minima criteria

Weather episodes with multiple landing minima parameters were typically longer than episodes with single landing minima criterion exceedances.[35] However, not all of these parameters occurred at the same time.

Twenty-four per cent of the time below the landing minima, more than one landing minima limit was exceeded. Figure 14 shows the number and percentage of total time and the number of aircraft arrivals expected during conditions below the landing minima by the combination of breached landing minima criteria. A complete break-down of weather episodes grouped by

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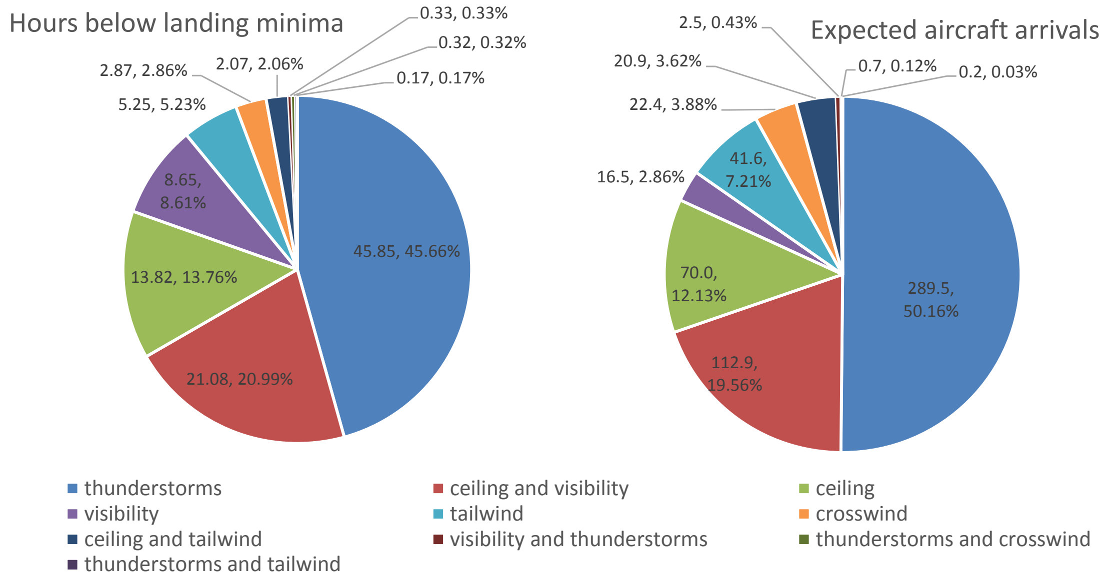
34 The *median absolute deviation* (MAD) is a non-parametric measure of the variability of a sample of data, roughly equivalent to 1.5 standard deviations in a normally distributed large population.

35 About 22 per cent of all episodes had more than one type of landing minima criterion exceeded. The observed conditions below the landing minima in these episodes (combining individual and multiple landing minima exceedances) made up 44 per cent of the total time below the landing minima at Adelaide Airport between 2009 and 2013.

landing minima combinations is shown in Appendix A – Selected TTF, TAF and METAR/SPECI results on page 153.

Figure 14: Landing minima parameter combinations observed simultaneously by total time and number of expected aircraft arrivals during conditions below landing minima at Adelaide Airport 2009 to 2013



Low visibility combined with low ceiling (shown in red on Figure 14) were the most prevalent combined parameters by duration below the landing minima, being more common than visibility or ceiling observed alone. Additionally, this was the second-most prevalent landing minima state behind thunderstorm activity. These conditions were observed together at Adelaide for about 21 hours over the 5 years, with approximately 113 aircraft were expected to arrive during these periods.

Of note at Adelaide were a number of tailwind (in lieu of visibility or ceiling on a reciprocal runway) and crosswind exceedances. For tailwind alone, a total of 5 hours and 15 minutes was observed at Adelaide between 2009 and 2013, and approximately 42 aircraft were expected to arrive during these times, and were generally associated with rain, mist and low cloud. Note that five episodes had durations of longer than 30 minutes below the landing minima.

Scenarios where wind limits were exceeded indicate where instrument approaches with varying precision on different runways had an effect. In these situations, it was not possible to land without breaching at least one landing minima criterion, however, *fewer* would be exceeded by accepting a landing above the nominated aircraft wind limitations. This typically involved scenarios where visibility and/or ceiling limits were exceeded for the instrument approach on an acceptable runway for wind, with visibility and/or ceiling being within limits for a runway direction with winds below landing minima limits.

For example, scenarios with both ceiling and tailwind indicate that the visibility limit would have also been exceeded for the wind-favoured runway. At Adelaide, the straight-in ILS runway 23 approach provides considerably lower visibility and ceiling limits than any other instrument approach, as a result, this was the most common selected approach in these scenarios.

Associated phenomena with landing minima criteria

Thunderstorms, rain and fog were the most prevalent weather phenomena at times when aircraft were unable to land at Adelaide Airport between 2009 and 2013.

Figure 15 shows all weather phenomena combinations and associated weather descriptors reported during periods below the landing minima. The upper graph shows the median duration of time each phenomena combination was reported within a weather episode. The upper and lower limits of the vertical lines show the variability around the median and show ± 1 median absolute deviation (MAD).[34]

The lower graph of Figure 15 show the total time below landing minima grouped by weather phenomena combinations (columns). Each of these phenomena combinations was divided into the combinations of landing minima criteria, as described in the *Combinations of landing minima criteria* section and shown in Figure 14 above.

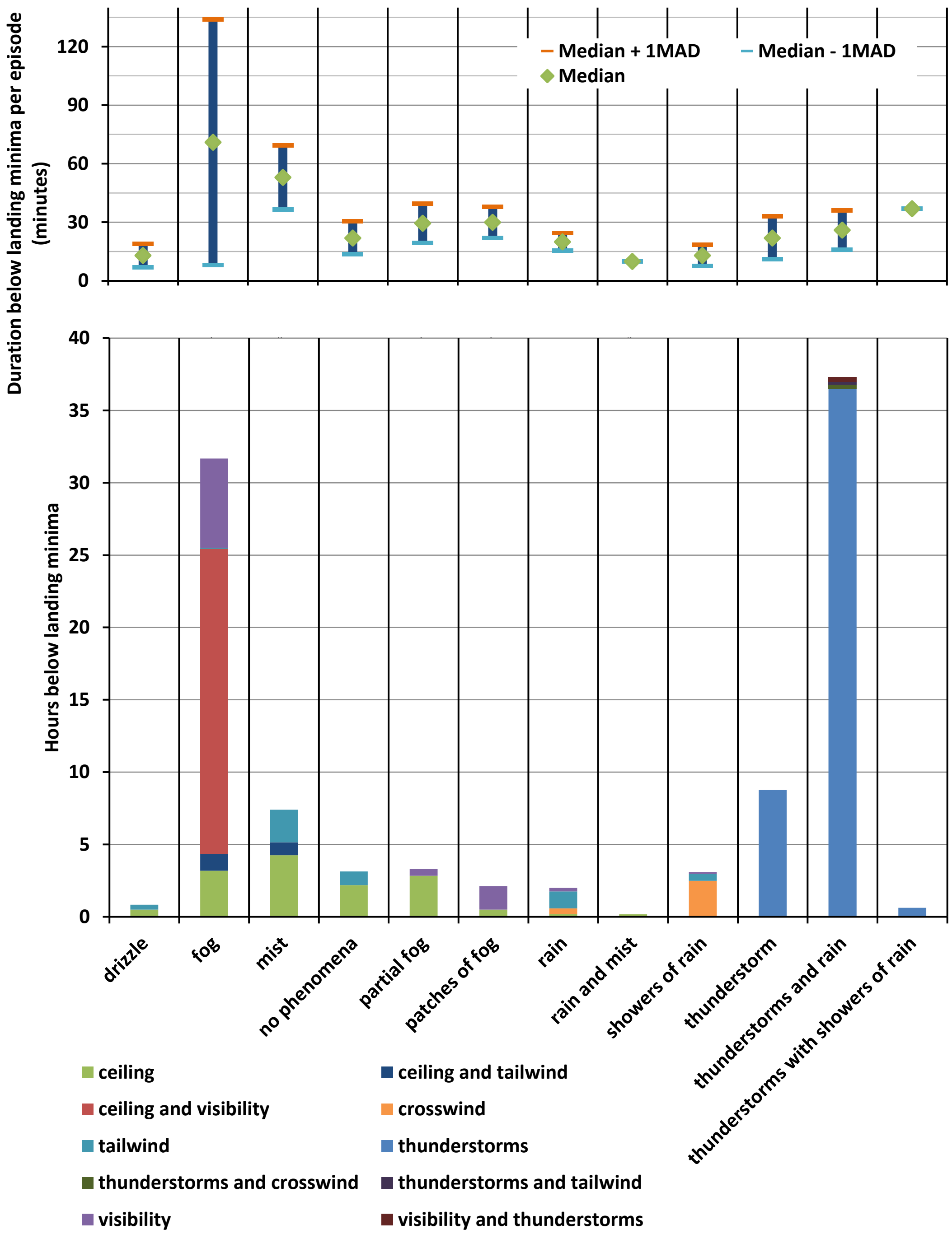
Most thunderstorms were reported with rain, and typically ranged between 16 and 36 minutes in duration. Due to thunderstorms being categorised as a weather descriptor and a landing minima criterion, a cross-tabulation of the same value is presented. In terms of landing minima criteria, thunderstorms largely appear as the sole reported minima, however, a small number of visibility and wind related breaches were identified.

Fog was second-most prevalent phenomena behind thunderstorms, with around 6 hours per year. These episodes had the largest variation and highest median duration, with half of ‘below minima fog episodes’ lasting for more than 1 hour 11 minutes, with a typical range between 8 minutes and 2 hours 24 minutes.

Conditions below the landing minima when fog was reported were generally longer than shown because of other phenomena combinations often being reported in the same weather episode. For example, fog occurred in all episodes below the landing minima where low cloud was reported, and also when fog was reported in patches or as partially covering the aerodrome. These conditions were typically related to conditions deteriorating to or improving from extended periods of fog, and is why these conditions are shorter in duration when compared with fog.

Fog was reported in all instances where both ceiling and visibility were reported at the same time below landing minima for all approaches at Adelaide, making up almost two-thirds of fog (reported as the sole phenomena) below the landing minima (shown in red in the lower graph of Figure 15).

Figure 15: Phenomena combinations observed during conditions below the landing minima – typical duration per episode (upper graph) and landing minima parameter combinations (lower graph), Adelaide Airport 2009 to 2013



Observed conditions below landing minima by phenomena and hour of day

Weather below the landing minima at Adelaide Airport occurred more commonly in the morning, with a distinct elevated period between the hours of 0500 and 1100 (shown by the dashed blue line in Figure 16). Peak times in conditions below the landing minima were mainly driven by elevated periods of fog and to a lesser extent, mist.

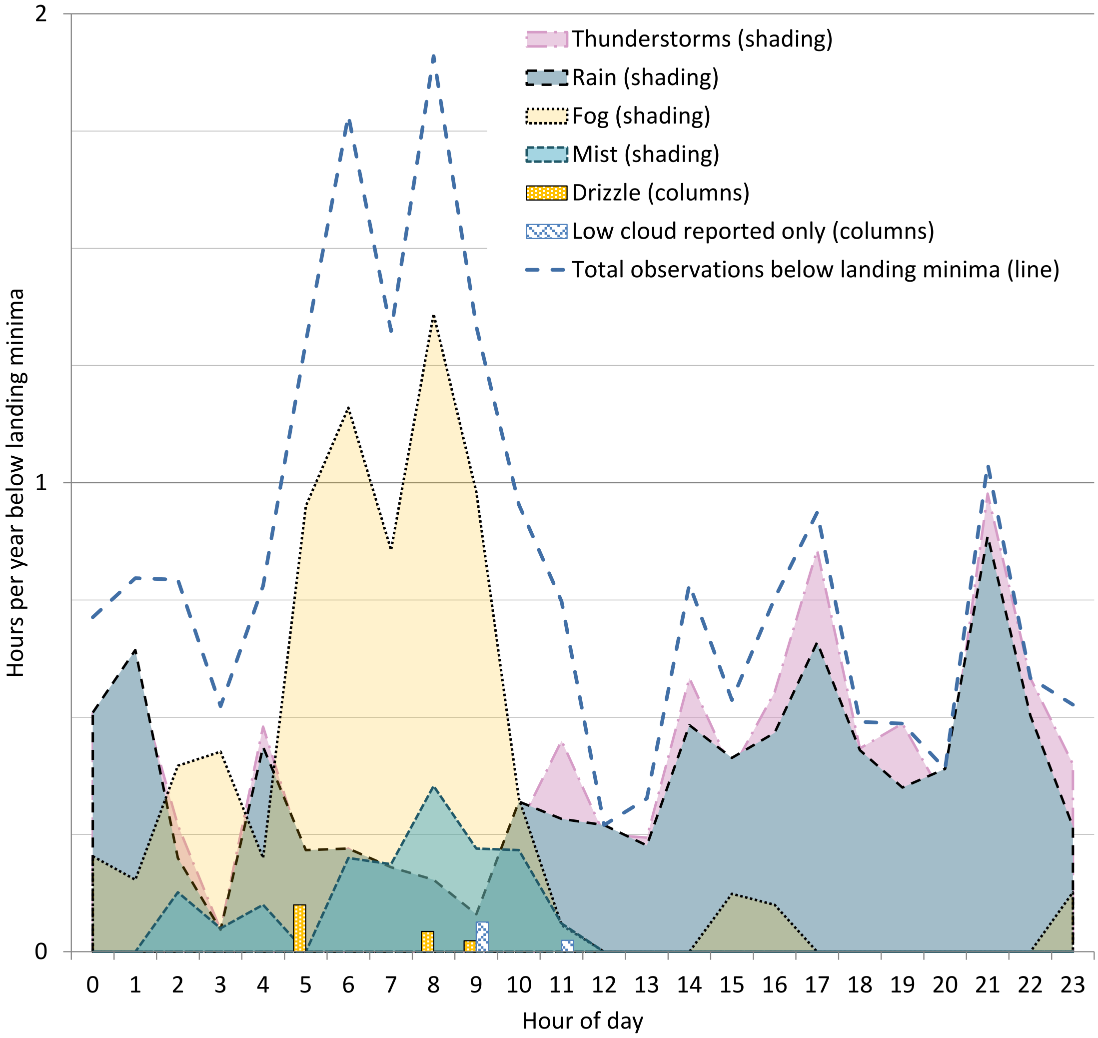
The remaining time fluctuated between 16 minutes per year from 1200 to 1300 to just over 1 hour per year between 2100 and 2200, with an average of 40 minutes. This was mainly the result of thunderstorm activity and rain.

Fog resulting in conditions below the landing minima was mainly observed between midnight through to 1200, with distinct peaks observed between 0600 to 0700, and 0800 to 0900. Conditions below the landing minima during fog was rare in the afternoon, although one period between 1500 and 1700 was identified on 26 July 2011.

Thunderstorms were generally observed throughout all hours of the day, with an elevated period from 1400 through to a peak between 2100 and 2200, with a trough between 0300 and 0400.

Mist was also observed in the morning, typically between 0600 and 1100.

Figure 16: Time of day of individual observed weather phenomena when conditions were below the landing minima at Adelaide Airport 2009 to 2013. Dashed blue line shows total time any observation was below the landing minima.



Observed conditions below landing minima by phenomena and month

There was distinctly more weather below the landing minima in Adelaide from 2009 to 2013 during the winter months June to August, and additionally, December. Two distinct peak months were June and August over this period.

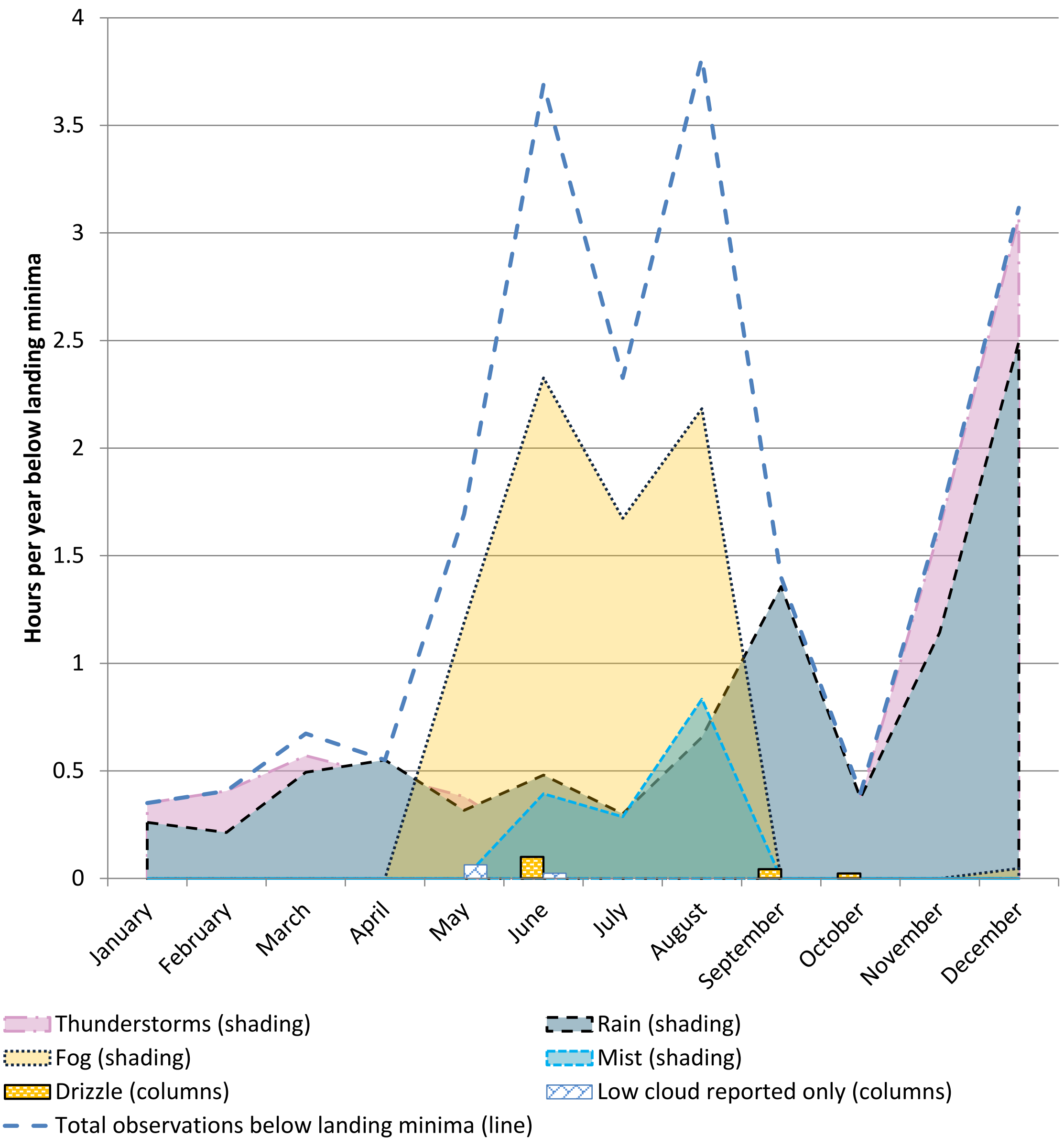
Winter weather peaks were driven by fog on a general baseline of thunderstorms, which occurred almost entirely between the months of May and August over the 5-year period. These peaks were also driven by all observed mist, which were entirely reported during the South Australian winter months.

Thunderstorms, typically with coincident rain (as shown in Figure 15), had a general baseline level throughout the year, although this was typically elevated in September, November and December.

The weather peak in December was driven almost entirely as a result of increased thunderstorm activity in that month.

The months providing the best weather conducive to an aircraft landing were October, and January to March between 2009 and 2013 at Adelaide.

Figure 17: Month of the year for individual observed weather phenomena when conditions were below the landing minima at Adelaide Airport 2009 to 2013. Dashed blue line shows total time any observation was below the landing minima.



The effect of forecasts on aircraft operations - Adelaide Airport

Adelaide Airport forecasts (TAFs and TTFs) were compared with meteorological reports (METARs and SPECIs) occurring at the times of forecast predictions between 2009 and 2013. These consisted of 8,698 TAFs, 91,685 TTFs,[36] 83,053 METARs and 9,094 SPECIs.

Comparisons were performed in accordance with *Comparisons between forecasts and observation reports* from page 31, divided into nine states, as described in *Measuring the operational reliability of weather forecasts* on page 25. In summary, aircraft operations are assumed to be affected by *observed* weather conditions *below the landing* minima, or *forecast* weather conditions *below the alternate* minima. These two effects are described as follows.

- A flight crew arriving during conditions below the landing minima would be unable to land within published safe thresholds.
- A flight crew retrieving a forecast that predicted conditions at the planned arrival time below the alternate minima are expected to have been alerted to potential unsuitable landing conditions. On this basis, if used for planning, additional fuel or other contingency plans could be formed to account for the expected deterioration in weather. If retrieved en route prior to the point of no alternate,[37] the forecast could provide sufficient warning to divert to an alternate aerodrome.

Weather episodes

Unprimed weather episodes refer to a weather episode[38] that includes a time where the forecast was above the alternate minima but had observations reported below the landing minima at the time an aircraft would have arrived at the destination. Weather episodes were formed by combining adjacent weather forecasts and observation reports together into common groups (see *Definitions and terms* on page 161).

Observed conditions below the landing minima

An average of 17 weather episodes per year (86 episodes in total) were identified with conditions below the landing minima at Adelaide Airport between 2009 and 2013. This equated to only 0.23 per cent of the time. However, due to the expected volume of aircraft arrivals during these times, approximately 577 aircraft (115 per year) were estimated to have been affected in some way during this time by unsuitable weather for landing. The typical phenomena, landing minima parameters and timing of these episodes are presented in *Overview of weather affecting aviation at Adelaide Airport* from page 42.

A further 35 weather episodes per year (174 over the five years) were observed where conditions were reported below the alternate minima, however, did not fall below the landing minima. When combined with conditions below the landing minima, all conditions below the alternate minima made up 0.71 per cent of all time at Adelaide Airport between 2009 and 2013. These proportions are represented by the yellow segment and expanded vertical column on the right side of Figure 18 on page 55 below.

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36 Of these TTFs produced, 65,244 were TTFs denoting no significant change (NOSIG), and 26,441 were TTFs predicting significant changes.

37 Geographical position on track or time at which fuel remaining becomes insufficient to reach an alternate aerodrome.

38 A *weather episode* is any period *outside* of when both the forecast AND observed weather were above the alternate minima (correct rejection).

Forecast conditions below the alternate minima – simulated retrieval zero to two hours prior to arrival and 2.5 hours prior to arrival

About 13 per cent of all TAFs and 8 per cent of all TTFs contained predictions of weather below the alternate minima for forecasts retrieved up to 2.5 hours prior to arrival. This equates to a total of 232 discrete TAFs per year and 1,495 discrete TTFs per year (averaged between 2009 and 2013) with predicted conditions below the alternate minima. Note that not all of these forecasts were available for each simulation due to *forecast availability*[39] periods.

Simulated forecast retrievals averaged for arrival zero to two hours later were performed to approximate the typical time that a flight crew may retrieve a forecast prior to the point of no alternate. This is expected to represent the best case scenario for forecast predictions that can be used by flight crews (degradation in forecast reliability occurs over time, as shown in *Forecast retrieval time comparisons* on page 78). Forecast retrievals 2.5 hours prior to arrival were selected to represent the largest duration of time that a TTF on a 30 minute release frequency could be reliability retrieved prior to arrival.

Forecasts triggering operational requirements (by prediction of conditions below the alternate minima) varied considerably between TAFs and TTFs, as shown in Table 5.

Table 5: Forecasts below the alternate minima - Number of expected aircraft arrivals and total elapsed time per year, averaged for simulated forecast retrievals 0 to 2 hours and 2.5 hours prior to arrival, Adelaide Airport 2009 to 2013

Simulated retrieval time prior to arrival	Forecast type	Forecasts below alternate minima		
		Total number of forecasts per year	Average duration per year (hours)	Expected number of aircraft arrivals per year
0 to 2 hours	TAF	232	622	3,413
	TTF	1,495	477	2,622
2 hrs 30 minutes	TAF	228	633	3,479
	TTF	1,221	478	2,618

Although there were considerably more TTFs released, TAFs had about 30 per cent more hours on average per year predicting conditions below the alternate minima.

In the hypothetical scenario where all arriving flight crews retrieved a TAF instead of a TTF 2 hours 30 minutes prior to arrival, 861 more arriving aircraft per year were expected to receive the prediction of conditions below the alternate minima. Most predicted conditions below the alternate minima were false alarms, as described in the next section.

Comparison of operational states of observations and forecasts

This section contains results of comparisons between observed operational states (from METARs and SPECIs) compared with actual forecast predictions (from TAFs and TTFs) averaged over nine simulations for forecast retrieval scenarios available between 0 and 2 hours prior to arrival (in 15 minute intervals).[40]

Duration of comparison states – forecast retrievals 0 to 2 hours prior to arrival

Figure 18 shows the nine comparison states of forecast and actual observed conditions (at the time the aircraft would arrive at the destination) as described in *Measuring the operational*

39 Described in *Forecast availability* on page 29.

40 Averaging between zero to 2 hours prior to arrival was chosen to indicate a typical period of time that flight crews are most likely to be affected, and also the best case scenario for forecast retrieval. However, there is further analysis of individual forecast retrieval time offsets below.

reliability of weather forecasts on page 25. It includes the overall likelihood of arriving at a time of unprimed observations below the landing minima.[41]

Unprimed observations below the landing minima (when conditions were forecast above the alternate minima, shown in red as a Miss in Figure 18) were very rare during the study period for both TAFs and TTFs (0.03% and 0.05% of the time respectively). However, when conditions were observed below the landing minima (about 0.23% of the time), 1 in every 7.7 minutes of active TAFs and 1 in every 4.3 minutes of active TTFs[42] predicted conditions above the alternate minima. When taking into account the number of discrete episodes, these occurred once in every 55 days for TAFs and once in every 38 days for TTFs on average.

The likelihood of a false alarm (where conditions were forecast to be below the alternate minima, however, were observed above), was significantly more likely than any time observed below the alternate minima no matter what forecast. TAFs were more conservative compared with TTFs, with approximately 6.6 per cent of all time for TAFs and 5.0 per cent of the time for TTFs during the study period containing false alarms. This indicates that the overall forecasting system at Adelaide is conservative in regard to the prediction of unsuitable weather for landing. Note that false alarm times shown in Figure 18 do not exclude periods occurring shortly after or prior to conditions below the alternate minima, and can be considered over-represented. This is discussed in *Expected distribution of aircraft arrivals by forecast comparison states – simulated forecast retrievals 0 to 2 hours prior to arrival* below.

A very small percentage of the time for forecasts/observations pairs (0.06% for TAFs and 0.09% for TTFs) were not decoded completely and excluded from the analysis. These appear to be evenly distributed across all comparison states and are not expected to affect the analysis. Further discussion of data validation can be found in *Validation of time fields* on page 38.

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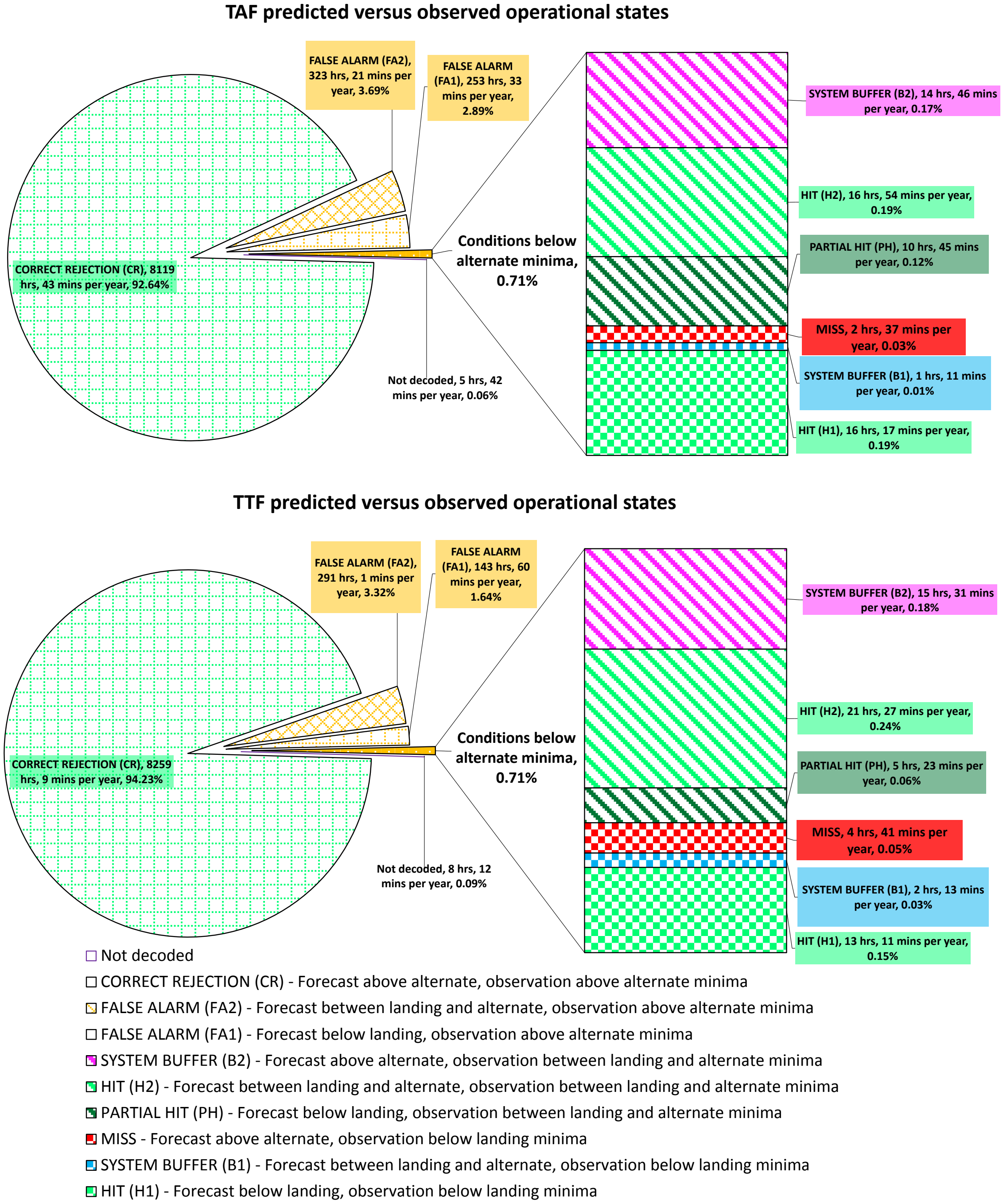
41 Observation of weather conditions below the landing minima preceded by a weather forecast (TAF or TTF) for conditions above the alternate minima.

42 Active forecasts include only those forecasts publically available and valid at a given time.

Figure 18: Percentage of total time and total time per year for TAF and TTF comparisons with observations – averaged for simulated forecast retrieval zero to 2 hours prior to arrival 2009 to 2013 – the overall likelihood of arriving at a time of unprimed observations below the landing minima was 0.03 per cent for TAFs and 0.05 per cent for TTFs overall, or 13 per cent and 23 per cent of all time below the landing minima respectively.



Expected distribution of aircraft arrivals by forecast comparison states – simulated forecast retrievals 0 to 2 hours prior to arrival

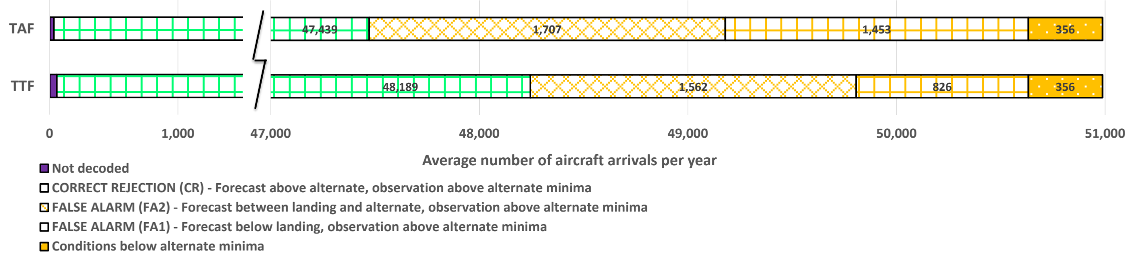
TAFs predicted considerably more conditions below the alternate minima when compared with TTFs over the same simulated time period, which is also reflected in the number of expected aircraft arrivals during these times. Figure 19 shows the breakdown of actual aircraft arrivals per year averaged between 2009 and 2013 divided by selected forecast comparison states for forecast retrievals on average between 0 to 2 hours prior to arrival. Categories are an abridged version of those presented in Figure 18. Two scenarios are presented:

- All aircraft arriving solely relying on *TAFs* in the forecast retrieval range.
- All aircraft arriving solely relying on *TTFs* in the forecast retrieval range.

False alarms (Figure 19 yellow hatching) were expected to create the largest operational differences for flight crews using one forecast over another. A difference of around 773[43] more aircraft arrivals with false alarms per year were expected for the scenario that all TAFs were used instead of TTFs (following the stipulated rule sets for each forecast[44]).

It is important to note that in the scenarios presented for simulated retrievals of a TAF or TTF averaged 0 to 2 hours prior to arrival, most aircraft are expected to be in the air during these times. Therefore, the uptake of additional fuel would probably not occur, although this may affect planning for continuation of flight. Additionally, false alarms presented include fine weather periods surrounded by conditions below the alternate minima.

Figure 19: Expected distribution of aircraft arrivals per year for sole use of TAF or TTF forecasts, simulations averaged for retrieval 0 to 2 hours prior to arrival, Adelaide Airport 2009 to 2013



Note that both TAF and TTF columns add to the *actual* number of aircraft arrivals per year, with the averaged simulations providing a *prediction* of the distribution of forecast comparison states (as shown in Figure 6), if one or the other scenario were applied. Between each observed operational state (i.e. above the alternate, between the alternate and landing, and below the landing minima), the expected number of aircraft arrivals is the same across simulations since these are fixed observations. However, there are some small errors due to decoding of data that result in slight variations in predictions between models.

The number of aircraft expected to arrive when conditions were observed below the alternate minima were considerably less than those expected to arrive during a forecast false alarm. However, 115 aircraft per year are expected to arrive during conditions below the landing minima, and a further 241 during conditions between the alternate and landing minima.

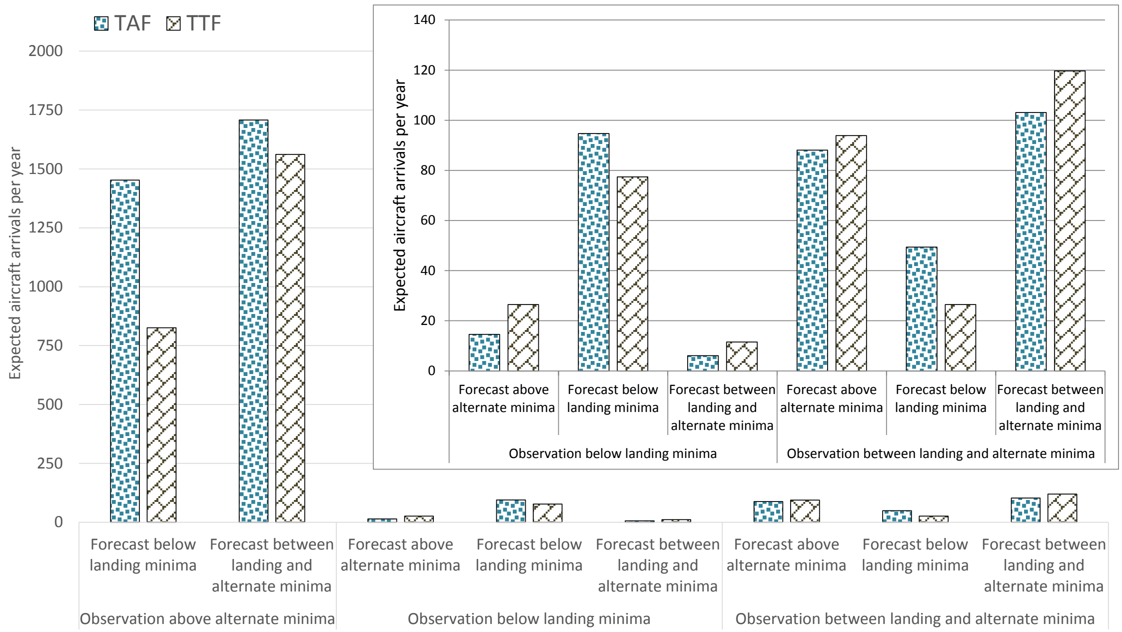
Differences in the expected distribution of aircraft arrivals when using all TAFs or all TTFs is shown in Figure 20 by forecast comparison state, an expansion of Figure 19. This compares TAFs and TTFs for all comparison states observed or forecast below the alternate minima. The inset graph on the right side of Figure 20 shows an expanded scale of *observed* conditions below the alternate minima. The left side of the graph shows false alarms for observations above the alternate minima, as already discussed.

Twenty-seven aircraft per year if using a TTF and 15 aircraft per year if using a TAF would be expected to arrive at Adelaide during an unprimed observation below the landing minima, for averaged simulations of retrievals 0 to 2 hours prior to arrival. This constitutes similar percentages (23 per cent for TTFs and 12.7 per cent for TAFs) to the expected unprimed durations below the landing minima shown in Figure 18.

[43] Due to rounding, a difference of 772 is shown in Figure 19.

[44] TAFs have associated 30 minute timing buffers added to any prediction below the alternate minima, as covered in *Stipulated contingency plans* on page 21.

Figure 20: Expected distribution of aircraft arrivals per year for sole use of TAF or TTF forecasts, simulations averaged for retrieval 0 to 2 hours prior to arrival (excluding correct rejections), Adelaide Airport 2009 to 2013



A ‘hit’ (forecast and observations between landing and alternate minima - Figure 6 code H2) was the most common forecast comparison state for both TAFs and TTFs by expected aircraft arrival following simulated retrieval out of any observed condition below the alternate minima (Figure 20). However, more aircraft would be expected to encounter this comparison state if using a TTF (120 expected arrivals per year) compared to using a TAF (103 expected arrivals per year).

Another common state for both forecast types was ‘forecast above the alternate minima’, when conditions were observed between the landing and alternate minima. This is categorised in Figure 6 as a ‘systemic buffer state’ (B2), and indicates where the buffer between the alternate and landing minima values of ceiling or visibility has been engaged. Around 90 aircraft per year would be expected to arrive during these marginal conditions without warning from a forecast (88 for a TAF, 94 for a TTF) retrieved 0 to 2 hours prior.

During conditions below the landing minima, the largest differences between unprimed aircraft arrivals following TAF or TTF retrievals were accounted for by a larger proportion of TAFs having forecasts below the landing minima (95 expected arrivals from TAFs compared to 77 expected arrivals from TTFs). There were also five fewer aircraft arrivals expected for TAFs compared with TTFs when the forecast was between the landing and alternate minima (Figure 6 - B1 system buffer).

The presence of aircraft arrivals during the system buffer (B1) state indicate the importance of using the alternate minima rather than the landing minima for operational decision making at Adelaide. Note that although only visibility and ceiling exist between the landing and alternate minima, this includes observed unprimed thunderstorms and strong winds where visibility and ceiling were forecast between the landing and alternate minima.

Timeline of unprimed operational state for sole use of TAF or TTF

Fifty-six out of 86 episodes were identified with an unprimed forecast period (shown as a ‘Miss’ in Figure 6), at Adelaide Airport for TAF and TTF retrievals two hours prior to arrival.

A timeline by monthly totals of these episodes for either TAF or TTF retrieval by number of expected aircraft arrivals and estimated unexpected holding time during these times is shown in

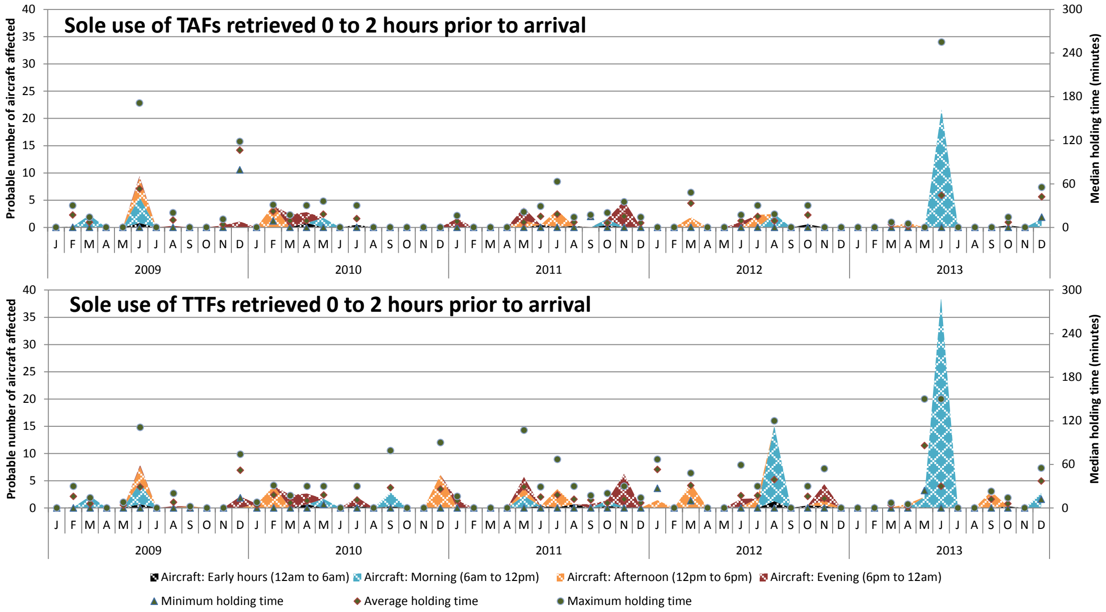
Figure 21. This shows two groups of hypothetical scenarios for forecast retrievals averaged 0 to 2 hours prior to arrival:

- sole use of TAFs
- sole use of TTFs.

Colours signify the expected aircraft arrivals by quadrant of day (left side scale), for example light blue signifies aircraft arrivals expected between 0600 and 1200.

The small dots in Figure 21 (right side scale) indicate the estimated unexpected median holding time (minimum (triangles), average (diamonds) and maximum (circles)) an aircraft may encounter after arriving during an unprimed observation. The calculation of these values is described in *Unexpected holding time range* on page 35.

Figure 21: Expected aircraft arrivals during unprimed observations ('Miss' as per Figure 6) estimated holding time after arrival by month, averaged for simulated forecast retrievals 0 to 2 hours prior to arrival, Adelaide Airport 2009 to 2013



Mornings in June 2013 at Adelaide Airport were expected to receive the largest number of aircraft arrivals between 2009 and 2013 during unprimed observations (following average simulated forecast retrieval 0 to 2 hours prior to arrival). This was driven by the weather episode on 18 June, as covered by ATSB investigation AO-2013-100.

For this episode, if all aircraft retrieved one type of forecast (TAF or TTF) between 0 to 2 hours prior to arrival:

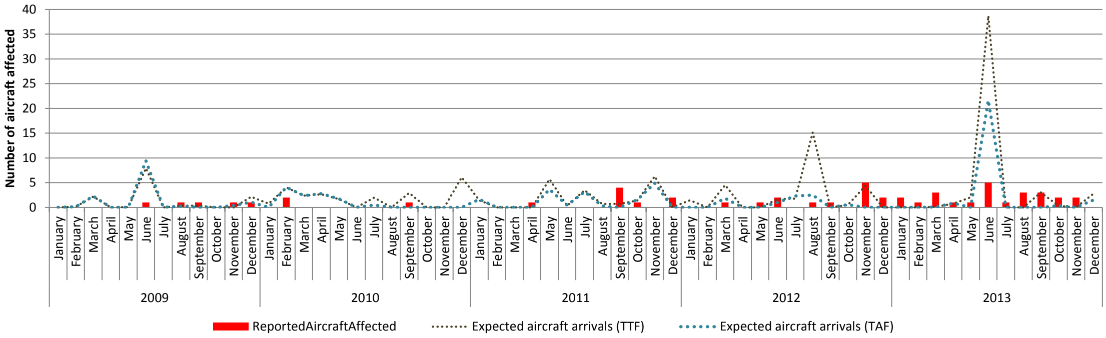
- more than 21 unprimed aircraft arrivals were expected when using a TAF, or
- more than 38 unprimed aircraft arrivals were expected when using a TTF.

Unexpected holding times varied over the five-year period, with a median average holding time of 12 minutes. However, in the scenarios presented (retrieval 0 to 2 hours prior to arrival) episodes in six months if using TTFs, and five months if using TAFs, were expected to have an unexpected holding time of 30 minutes or more (taking the median of the average of each episode).

Similar patterns in expected unprimed aircraft arrivals between TAFs and TTFs were exhibited in most months over the five-year period. One notable exception was on 7 December 2010 (see Table 6), where on average around five aircraft were expected to arrive during an unprimed state if using a TTF, with none expected for simulated TAF retrievals.

An overlay of these patterns are shown in Figure 22. This is the total TAF and TTF expected aircraft arrivals data shown in Figure 21.

Figure 22: Expected aircraft arrivals during unprimed observations ('Miss' as per Figure 6) averaged for simulated forecast retrievals 0 to 2 hours prior to arrival, and reported number of aircraft in weather related safety occurrences, Adelaide Airport 2009 to 2013



The red columns in Figure 22 show the number of aircraft reported in weather related safety occurrences to the ATSB at Adelaide. Notably fewer aircraft occurrences were reported than the number of expected arrivals (if using either TAFs or TTFs), however, this was expected to be related to the following factors.

- Planned aircraft arrivals during unprimed forecasts not being reportable to the ATSB due to these encounters not resulting in a transport safety matter. These may include:
  - in-flight diversions to another location
  - returning to the departure aerodrome
  - have sufficient fuel to hold with fuel reserves intact
  - being able to land if conditions below the landing minima were intermittent, less severe or close to the published limits.
- Under-reporting of some safety related incidents.
- Uncertainty in the expected aircraft arrivals model.

A moderate to strong positive correlation by day existed between TAFs and TTFs for expected unprimed aircraft arrivals if each forecast was retrieved up to 2 hours prior to arrival.[45] This indicates a strong linear relationship between the expected unprimed arrivals of these two forecasts - when an unprimed arrival using a TTF was expected, it was common that an unprimed arrival using a TAF would also be expected on the same day.

In all but 2 of the 56 individual unprimed episodes for simulated TAF or TTF retrievals 2 hours prior to arrival,[46] TTFs had the same or longer (24 episodes) duration of unprimed observations when compared to TAFs. Table 6 shows 10 weather episodes with the highest number of expected aircraft arrivals, averaged between unprimed TAF and TTF retrievals 2 hours prior to arrival.

The left side of Table 6 shows characteristics of the observations below the landing minima (also shown in Table 4). For the left side observations, the blue bars under the duration column, and yellow bars under the expected aircraft arrivals column are proportional representations of each parameters maximum value, in this case 7 December 2010, with almost 56 aircraft expected to arrive during the 8.73 hours of reported thunderstorms.

[45] r = 0.81 between simulated aircraft arriving with unprimed TAFs and TTFs, retrieval 0 to 2 hours prior to arrival.

[46] Note the individual forecast retrieval simulations are compared as these represent discrete time periods.

Table 6: Top 10 weather episodes with unprimed observations ordered by number of expected aircraft arrivals during unprimed states – TAF and TTF retrievals 2 hours prior to arrival

Observations below landing minima							Unprimed states							
											Duration (hours)		Expected aircraft arrivals	
Date	Start time	End time	Duration (hours)	Expected aircraft arrivals	Phenomena	Landing minima breached	TAF Start time	TAF End time	TTF Start time	TTF End time	TAF	TTF	TAF	TTF
18-Jun-13	7:45 AM	12:00 PM	4.25	42.40	partial fog	ceiling and visibility	7:45 AM	12:00 PM	7:45 AM	12:00 PM	2.77	4.25	27.70	42.40
26-Jul-11	3:23 PM	4:30 PM	1.12	9.40	partial fog	ceiling and visibility	3:23 PM	4:30 PM	3:23 PM	4:30 PM	1.12	1.12	9.40	9.40
03-Dec-13	11:00 AM	11:55 AM	0.92	9.50	thunderstorms and rain	thunderstorms	11:00 AM	11:41 AM	11:00 AM	11:55 AM	0.68	0.92	7.10	9.50
16-Dec-09	8:46 PM	1:30 AM	3.52	13.00	thunderstorms and rain	thunderstorms	8:46 PM	9:25 PM	8:46 PM	10:30 PM	0.65	1.73	4.90	10.50
03-Aug-12	5:00 AM	11:18 AM	6.30	46.40	fog and mist	ceiling, visibility and tailwind	11:00 AM	11:18 AM	5:00 AM	11:18 AM	0.30	2.30	2.50	10.90
14-Mar-12	2:12 PM	7:21 PM	2.25	24.20	thunderstorms and rain	thunderstorms	2:12 PM	3:00 PM	2:12 PM	3:00 PM	0.80	0.80	6.60	6.60
07-Dec-10	1:30 PM	2:00 AM	8.73	55.70	thunderstorms and rain	thunderstorms	N/A	N/A	1:30 PM	3:30 PM	0.00	1.50	0.00	11.90
30-Jun-09	10:05 AM	10:30 AM	0.42	4.80	thunderstorms and rain	thunderstorms and crosswind	10:05 AM	10:30 AM	10:05 AM	10:30 AM	0.42	0.42	4.80	4.80
12-Jul-12	2:30 PM	3:00 PM	0.50	4.60	thunderstorm	thunderstorms	2:30 PM	3:00 PM	2:30 PM	3:00 PM	0.50	0.50	4.60	4.60
10-Feb-10	4:27 PM	5:00 PM	0.55	4.10	thunderstorm	thunderstorms	4:27 PM	5:00 PM	4:27 PM	5:00 PM	0.55	0.55	4.10	4.10

The right side of Table 6 shows the results of simulating TAF and TTF retrievals 2 hours prior to arrival during the times of each listed weather episode. TAF and TTF start and end times correspond to when the first and last unprimed state, and the duration, indicates the length of time that the unprimed state would have been observed. Note that the time difference between the start and end is sometimes longer than the unprimed duration, indicating periods of other forecast comparison states, such as a 'Hit' (see Figure 6) or periods of improved weather.

Yellow shading in the unprimed duration columns indicate the longer unprimed duration between TAF and TTF (5 of 10 episodes have longer durations with unprimed TTFs). No shading indicates where the unprimed duration is the same.

Expected aircraft arrivals are shaded to indicate scale – red is the largest number (TTFs on 18 Jun 2013) – yellow are mid-range aircraft affected (for example 26 July 2011), and green indicates lower numbers.

For some unprimed weather episodes for simulated TAF or TTF retrieval 120 minutes prior to arrival, no prediction was present for the entirety of observations below the landing minima, for example on 26 July 2011. In other episodes such as 16 December 2009, part of the period is predicted. In this case, the unprimed TAF prediction commences at 1100 for 18 minutes (indicating that fog and mist remained for longer than anticipated).

Yearly trends

Each year, an average of 9.7 weather episodes associated with unprimed TTFs retrieved between 0 to 2 hours prior to arrival occur. An average of 6.6 weather episodes were expected for unprimed TAFs retrieved under the same scenario.

Yearly averages of episodes are shown as numbers on top of the columns in Figure 23. The columns (left side scale) represent time below the landing minima by total (hollow columns), unprimed TAF (aqua columns) and unprimed TTF (olive columns). Shading (right side scale) represents the number of expected planned aircraft arrivals after retrieving an unprimed TAF or TTF. The number of aircraft arrivals (estimate for 2009) are shown for reference as the line.

A larger number of aircraft arrivals and unprimed observations were expected for TTF compared with TAF retrievals between 0 to 2 hours prior to arrival for all years except 2009. This is discussed in the previous section.

The year 2013 had the highest number of aircraft expected to arrive if either a TAF or TTF was used. This was driven largely by the weather episode on 18 June and a slight increase in aircraft activity. The timing of this episode in the morning resulted in a higher proportion of aircraft affected when compared with the unprimed duration of time below the landing minima for both TAF and TTFs. In general, the time of arrival and time of year significantly affect the likelihood of retrieving an unprimed forecast, as shown in the following sections.

The average rate of weather episodes with unsafe conditions was calculated to be 19 per 100,000 arrivals for TTFs and 13 per 100,000 arrivals for TAFs. This equates to 1 in around 5,000 arrivals for TTFs and 1 in 7,700 arrivals for TAFs.

Figure 23: Hours of unprimed and primed observations below the landing minima by year, averaged over retrieval periods zero to 2 hours prior to arrival. Column labels indicate the number of weather episodes for each category. Lines represent actual total aircraft arrivals[47] and expected aircraft arrivals during unprimed observations.

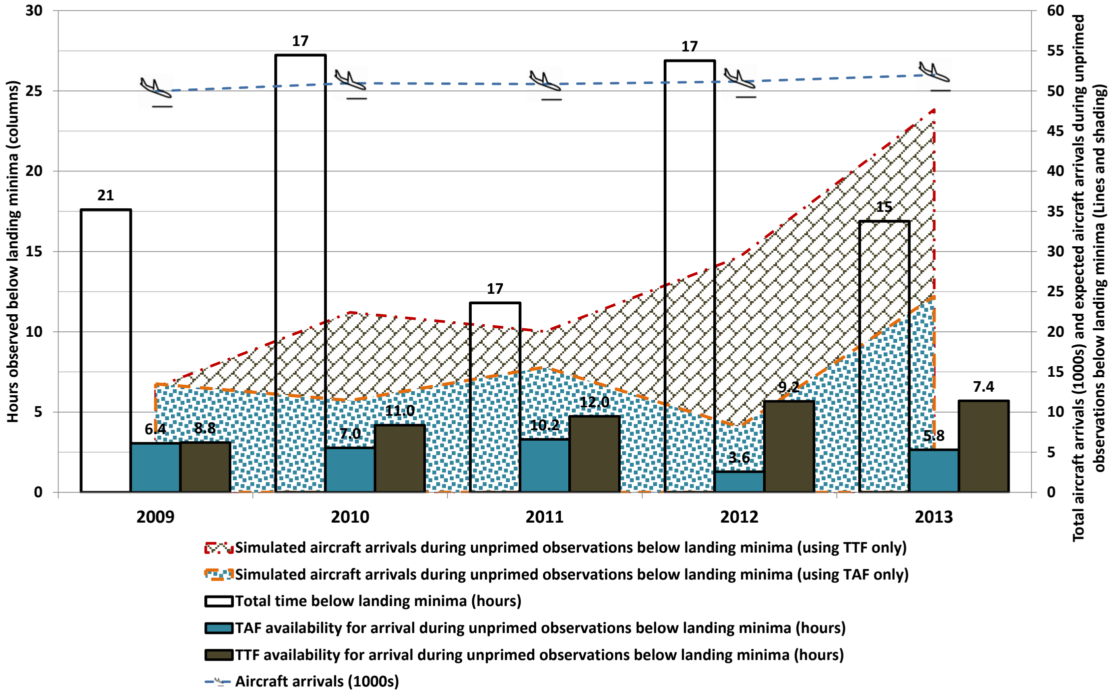


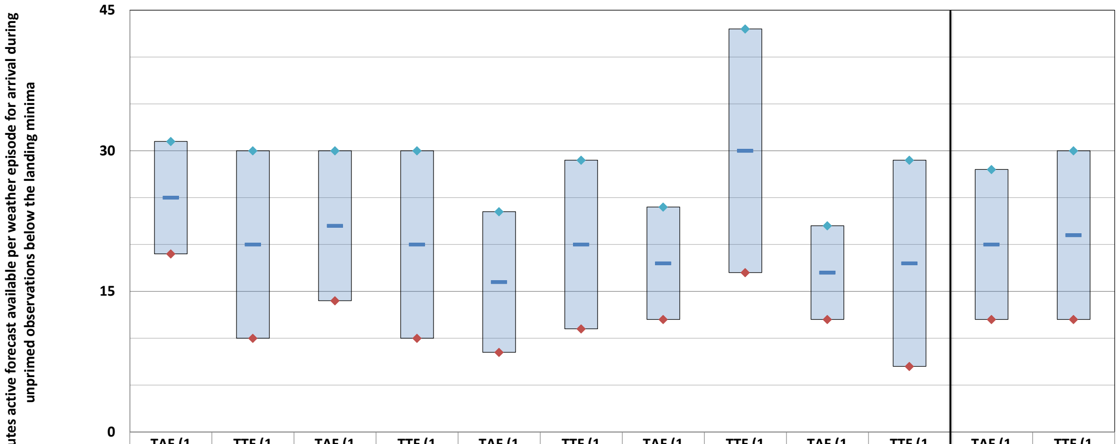
Figure 24 shows the median time a forecast was available, per weather episode, where an aircraft could have arrived during unprimed observations below the landing minima. The average frequency of these weather episodes with unprimed observations is displayed by year and forecast type in the horizontal-axis label. For example, in 2009, episodes with unprimed TAFs occurred about 1 in every 57 days. Maximum and minimum durations are shown in the table below. It is also important to note that there was significant monthly and hourly variation in likelihood which is explored below.

The differences across years were relatively small and only had a slight effect on the overall likelihood of arriving during unprimed observations below the landing minima after retrieving a forecast. When there were unprimed observations below the landing minima at Adelaide, the median time that those forecasts were available was 20 minutes per unprimed TAF episode or 21 minutes per unprimed TTF episode, occurring once in every 55 days and once in every 38 days respectively.

The largest variation and duration of unprimed episodes were for TTFs in 2012, with a median of 30 minutes.

47 Aircraft arrivals data were only available between 2010 and 2013, aircraft affected for 2009 was calculated in the same way as other years except these data were normalised using the interpolated arrivals for 2009.

Figure 24: Typical time a forecast was available, per weather episode, where an aircraft could have arrived during unprimed observations below the landing minima, by year and type of forecast, averaged for simulated retrievals zero to 2 hours prior to arrival



	TAF (1 episode in 56.6 days)	TTF (1 episode in 41.6 days)	TAF (1 episode in 52.1 days)	TTF (1 episode in 33.2 days)	TAF (1 episode in 35.7 days)	TTF (1 episode in 30.4 days)	TAF (1 episode in 102.9 days)	TTF (1 episode in 39.7 days)	TAF (1 episode in 63.2 days)	TTF (1 episode in 49 days)	TAF (1 episode in 55.3 days)	TTF (1 episode in 37.7 days)
	2009		2010		2011		2012		2013		Total	
Median	25	20	22	20	16	20	18	30	17	18	20	21
Median - 1 MAD	19	10	14	10	8.5	11	12	17	12	7	12	12
Maximum	70	104	38	90	67	111	48	138	166	255	166	255
Minimum	4	2	10	3	2	2	2	2	5	2	2	2
Median +1 MAD	31	30	30	30	23.5	29	24	43	22	29	28	30

Time of day

Variation in aircraft arrivals and unprimed forecast states (Figure 6) throughout the hours of the day resulted in considerable differences between the numbers of aircraft expected to arrive after retrieving an unprimed TAF or TTF. This is shown as the shaded areas in Figure 66 the simulated sole retrieval of TAFs or TTFs averaged 0 to 2 hours prior to arrival.

Figure 25: Hours active forecasts were available for unprimed and primed observations below the landing minima (columns), thousands of aircraft arrivals (blue line), and expected aircraft arrivals during unprimed observations below the landing minima (shading) per year, by hour of day, averaged for simulated TAF and TTF retrieval times between zero to 2 hours prior to arrival 2009 to 2013. Column labels indicate the number of weather episodes per year for each category and are additive.

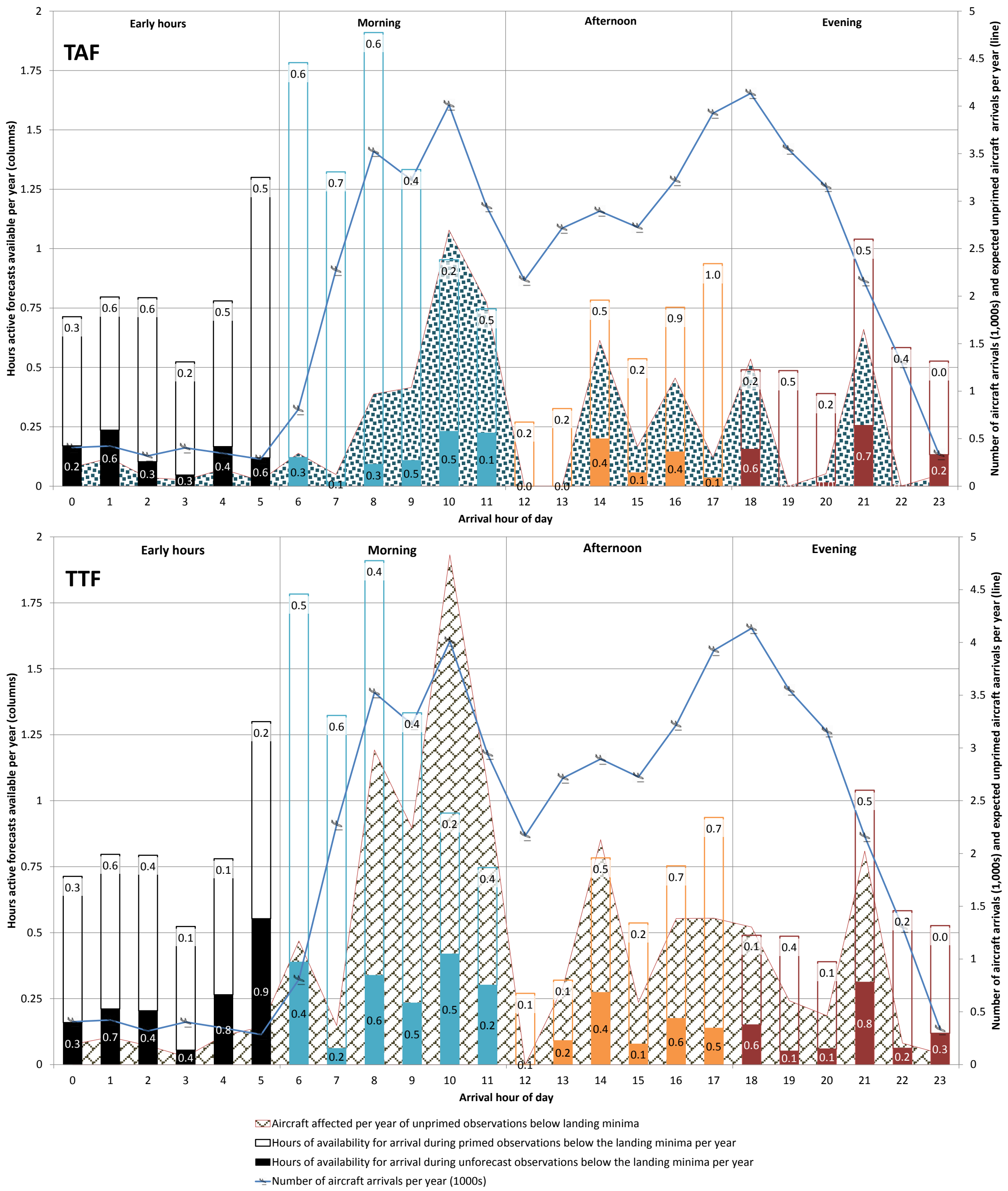


Figure 25 also shows both unprimed (solid columns) and primed (transparent columns) observations below the landing minima across the 24 hours of the day for simulated TAF and TTF retrieval averaged from 0 to 2 hours prior to arrival.

Unprimed TAFs and TTFs produced a similar pattern of expected aircraft arrivals by hour under the same simulated conditions. TTFs had a larger number of expected unprimed aircraft arrivals for all hours (and the vast majority of episodes), as identified on page 59.

Between 1000 and 1200, the largest number of unprimed aircraft arrivals were expected for both TAFs and TTFs, with other elevated periods observed from 0800 to 1200 and 1400 to 2200.

Lower number of expected unprimed aircraft arrivals were observed between 2200 and 0600, and 1200 to 1400. The lower period in the early hours was generally related to period of reduced aircraft traffic, whereas lower unprimed observations and in general a lower proportion of weather below the landing minima was expected to contribute to the low period between 1200 and 1400.

When considering unprimed observations alone, 1000 to 1100, and 2100 to 2200 for TAFs and 0500 to 0700 and 1000 to 1100 for TTFs had the longest duration of unprimed observations per year (shown as solid columns in Figure 25). Another way of phrasing this is that these are the most likely times to arrive with an unprimed forecast retrieved 0 to 2 hours prior to arrival.

Figure 26 below displays the same columns as Figure 25 but as 100 per cent for each hour of day, so that the percentage of unprimed observations compared with all observations below landing minima can be more easily seen. The line in Figure 26 displays the percentage of total time below the landing minima by hour to give a reference of the peak weather times of day.

The largest percentage of unprimed TTFs was expected between 0400 and 0600, and 1000 to 1200, when compared with all observations below landing minima during these hours. These periods occurred on either side of the main weather peak period for Adelaide (outlined in in Figure 26), corresponding to the main period of fog, mist and low cloud (Figure 16 on page 50). In contrast, considerably lower percentage of unprimed TTFs (compared with all observations below landing minima) were expected during the peak weather period between 0600 and 1000. TAFs also exhibited the same characteristics as TTFs, although to a diminished extent.

This may indicate that while the typical weather phenomena and conditions associated with this peak are able to be readily predicted, determining when the weather will start and how long it will remain proves to be more problematic. This is explored in *Characteristics of unprimed observations at Adelaide Airport* on page 85.

Generally, unprimed percentages ranged from 0 to more than 40 per cent for TTFs, and more than 30 percent for TAFs, compared with total hourly observations below the landing minima were identified. However, TTFs had consistently higher unprimed percentages for each hour.

Figure 26: Unprimed observations as a percentage of all time below the landing minima for each hour of day, averaged for simulated TAF and TTF retrieval times zero to 2 hours prior to arrival, 2009 to 2013

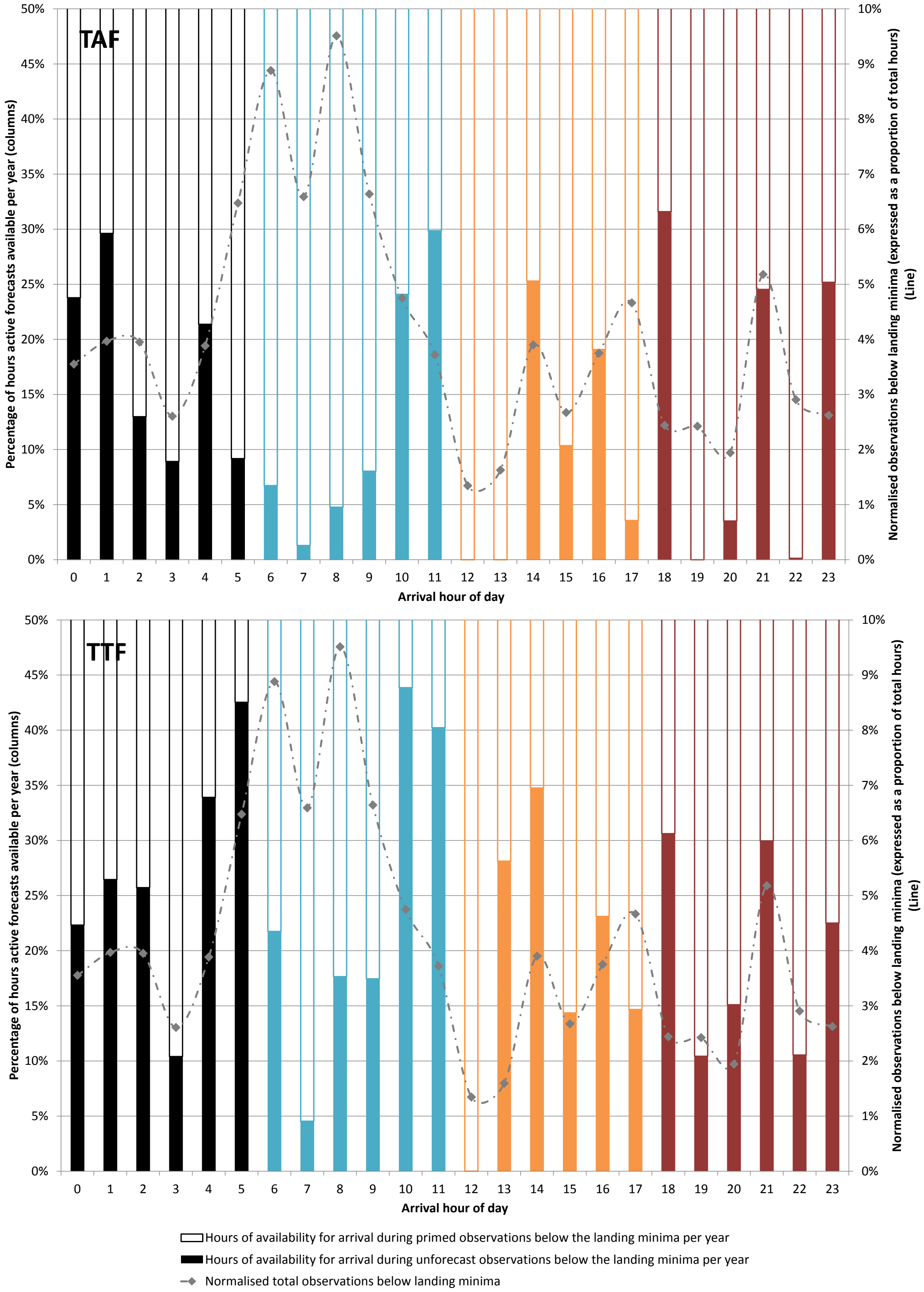
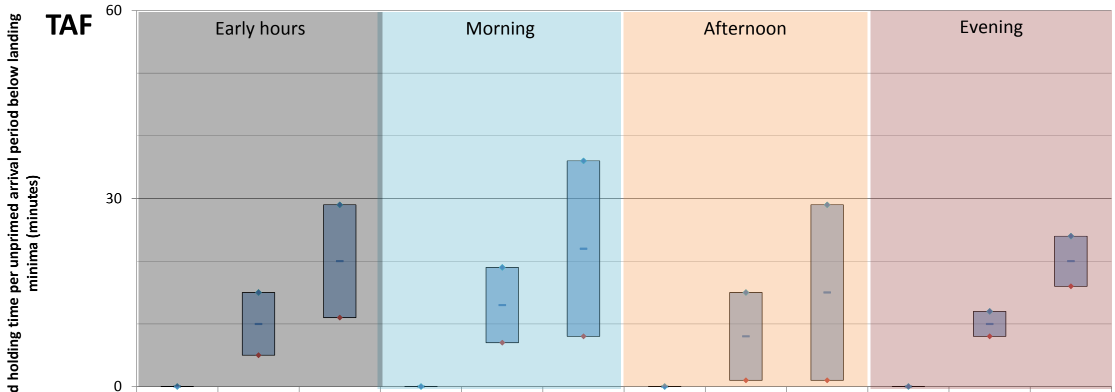


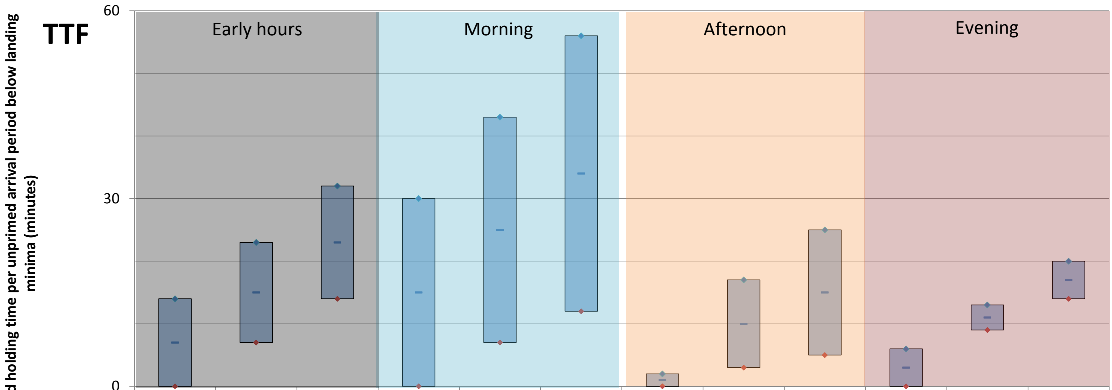
Figure 27 shows the estimated average (middle bars), minimum (left bars) and maximum (right bars) aircraft holding time for each quadrant of the day. Estimated holding time is the time that an aircraft would have to expectantly hold following arrival in conditions below the landing minima after the retrieval of a forecast above the alternate minima. It takes into account the forecast that a flight crew would have received and the time observations remain below the landing minima after arrival and/or a change in the forecasted conditions in the same TAF after arrival. See *Unexpected holding time range* on page 35 for more details.

Figure 27 shows that mornings had longer estimated holding times, and a greater variation in holding times, than the other times of the day when using a TAF or TTF. Half of all unprimed arrival periods in mornings had an average holding time greater than 13 minutes for TAFs and 25 minutes for TTFs, the highest of all quadrants of the day. The relatively large variation in holding times for mornings means that for some episodes, in particular TTFs, holding may range from under 10 minutes to well above 30 minutes in duration.

Figure 27: Estimated holding time for episodes with unprimed observations below landing minima for each quadrant of day, averaged for simulated TAF and TTF retrieval times zero to 2 hours prior to arrival 2009 to 2013[48]



	Minimum Early hours (0000 to 0600) (n = 12)	Average Early hours (0000 to 0600) (n = 12)	Maximum Early hours (0000 to 0600) (n = 12)	Minimum Morning (0600 to 1200) (n = 8)	Average Morning (0600 to 1200) (n = 8)	Maximum Morning (0600 to 1200) (n = 8)	Minimum Afternoon (1200 to 1800) (n = 5)	Average Afternoon (1200 to 1800) (n = 5)	Maximum Afternoon (1200 to 1800) (n = 5)	Minimum Evening (1800 to 0000) (n = 8)	Average Evening (1800 to 0000) (n = 8)	Maximum Evening (1800 to 0000) (n = 8)
Median	0	10	20	0	13	22	0	8	15	0	10	20
Median - 1 MAD	0	5	11	0	7	8	0	1	1	0	8	16
Maximum	90	105	120	254	255	255	57	61	63	120	146	171
Minimum	0	2	3	0	4	7	0	1	1	0	2	4
Median + 1 MAD	0	15	29	0	19	36	0	15	29	0	12	24



	Minimum Early hours (0000 to 0600) (n = 17)	Average Early hours (0000 to 0600) (n = 17)	Maximum Early hours (0000 to 0600) (n = 17)	Minimum Morning (0600 to 1200) (n = 11)	Average Morning (0600 to 1200) (n = 11)	Maximum Morning (0600 to 1200) (n = 11)	Minimum Afternoon (1200 to 1800) (n = 9)	Average Afternoon (1200 to 1800) (n = 9)	Maximum Afternoon (1200 to 1800) (n = 9)	Minimum Evening (1800 to 0000) (n = 11)	Average Evening (1800 to 0000) (n = 11)	Maximum Evening (1800 to 0000) (n = 11)
Median	7	15	23	15	25	34	1	10	15	3	11	17
Median - 1 MAD	0	7	14	0	7	12	0	3	5	0	9	14
Maximum	135	143	150	135	143	150	75	83	90	90	101	111
Minimum	0	2	4	0	1	2	0	1	1	0	3	5
Median + 1 MAD	14	23	32	30	43	56	2	17	25	6	13	20

[48] Median holding times were calculated from estimated holding times for each unprimed hour within each daily quadrant.

TAFs were expected to produce a lower overall effect per unprimed episode when compared with TTFs with regard to unexpected holding time. However, throughout the day, particularly in the morning, there have been weather episodes when the estimated holding was be longer than standard fuel reserves of arriving aircraft (usually between 20 and 45 minutes[49]).

Monthly trend

Unprimed forecasts also varied considerably across the months of the year at Adelaide Airport. Figure 28 shows data across the 12 months of the year, separated for each quadrant of the day in the same categories and format as Figure 25 showed hour of day variation on page 64.

As identified in Figure 17, an increased prevalence of unsuitable landing conditions occurs in the winter months, between June to August, and in December. This is reflected in the columns of Figure 28, showing the unprimed (solid columns) and primed (hollow columns) by the quadrant of the day that they occur.

For the winter months, the largest peaks in conditions below the landing minima occurred in the morning at Adelaide between 2009 and 2013, followed by the early hours.

Although mornings in August had considerably more weather below the landing minima (about 2.9 hours in August mornings per year), June mornings had the highest duration of unprimed observations for both TAFs (30 minutes per year) and TTFs (51 minutes per year). Accordingly, June mornings had the highest peak in the number of expected unprimed aircraft arrivals for both TAFs (5.5 arrivals per year) and TTFs (8.8 arrivals per year).

A general baseline of expected unprimed aircraft arrivals was present in afternoons between the months of February and July.

In the evenings, November had the longest number of unprimed observations and expected unprimed aircraft arrivals for both TAFs and TTFs (Figure 28) out of any month. This is despite not having a relatively long duration of observations below the landing minima (Figure 17)..

Notably larger numbers of expected aircraft arrivals following retrieval of an unprimed TTF can be clearly seen for some months and quadrants of the day. For example, mornings in August, afternoons in September and December, and evenings in November all have elevated expected unprimed aircraft arrivals for TTFs when compared with TAFs.

Expected unprimed aircraft arrivals were least probable during the early hours when using either forecast (TAFs or TTFs) because of the considerably smaller numbers of reported arrivals during this these times.

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[49] An additional variable reserve of up to 15 per cent applies to some aircraft – see Civil Aviation Advisory Publication CAAP 234-1, *Guidelines for aircraft fuel requirements*, for details.

Figure 28: Hours active forecasts were available for unprimed and primed observations below the landing minima (columns), thousands of aircraft arrivals (blue line), and expected aircraft arrivals during unprimed observations below the landing minima (shading) per year, by month for each quadrant of day, averaged for forecast retrieval times between zero to 2 hours prior to arrival 2009 to 2013. Column labels indicate the number of weather episodes per year for each category and are additive.

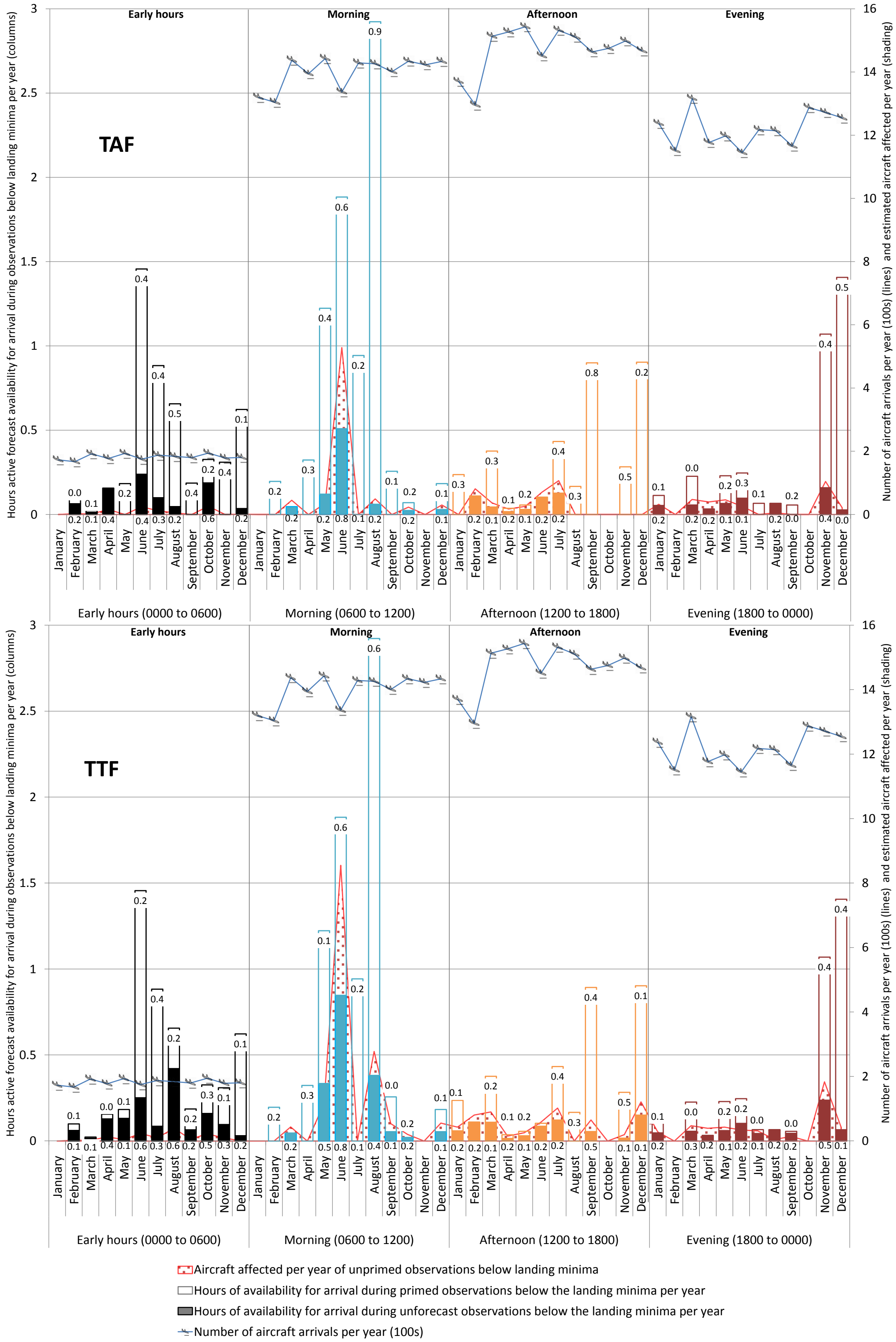


Figure 29 below shows the same columns as Figure 28, in the same format as described for Figure 26, so that the percentage of unprimed observations compared with all observations below landing minima can be more easily seen. The line in Figure 29 displays the percentage of total time below the landing minima by month and quadrant of day to give a reference of the fluctuations in observations below the landing minima.

Unprimed TAFs and TTFs making up more than 50 percent of observations below the landing minima were identified for some quadrants of day in some months. This means that more than half of the time below the landing minima was not forecast. However, in all but one month and quadrant of day, this constituted less than one per cent of the total time below the landing minima, or about 12 minutes per year.

The exception to this was for simulated TTF retrievals in the early hours of August, where about 25 minutes of the 39 minutes per year was unprimed. However, due to lower total aircraft arrivals during the early hours, a small number of aircraft arrivals were expected (about 2 unprimed aircraft arrivals every 5 years).

Notable periods were identified by month and quadrant making up more than five per cent of the total time below the landing minima (about 1 hour per year), and percentages of unprimed observations exceeding 1 in every 5 minutes of observations below the landing minima in each group. Periods identified (as shown in Figure 28 and Figure 29) were:

- June mornings
    - 27.0 per cent unprimed TAFs (31 minutes unprimed out of 113 minutes per year)
    - 45.0 per cent unprimed TTFs (51 minutes unprimed out of 113 minutes per year)
- May mornings – 27.3 per cent unprimed TTFs
- November evenings – 22.2 per cent unprimed TTFs.

Figure 29: Unprimed observations as a percentage of all time below the landing minima for each month and quadrant of day, averaged for simulated TAF and TTF retrieval times zero to 2 hours prior to arrival, 2009 to 2013

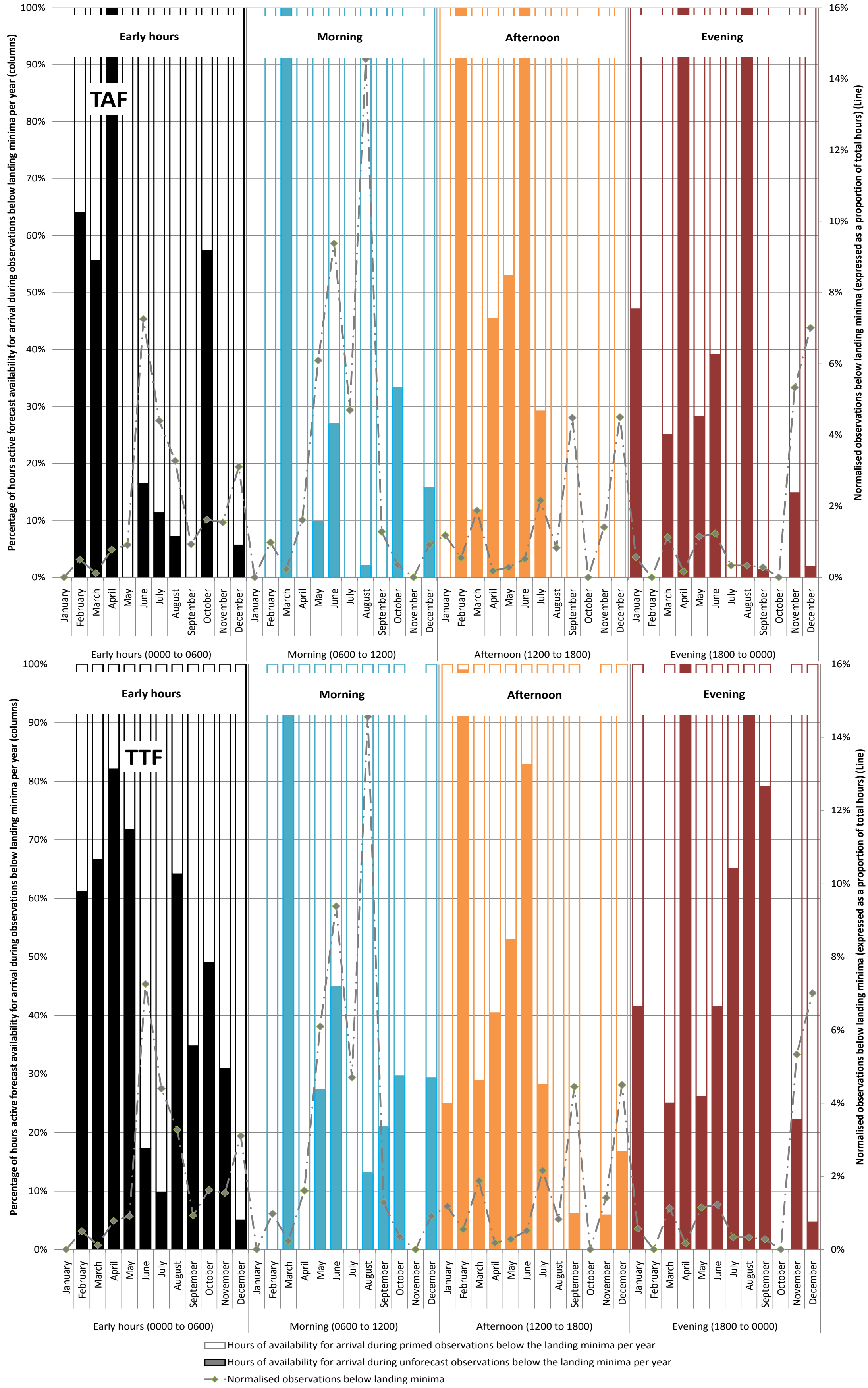


Figure 30 shows the median estimated holding times that an aircraft was expected to encounter after arriving during an unprimed observation below landing minima. As described in *Unexpected holding time range* on page 35, each holding period has three calculated values – minimum, average and maximum. This is indicated by the blue bars, which display the monthly medians from a combined dataset of 15 minute increments of forecast retrieval time prior to arrival from zero to 2 hours.

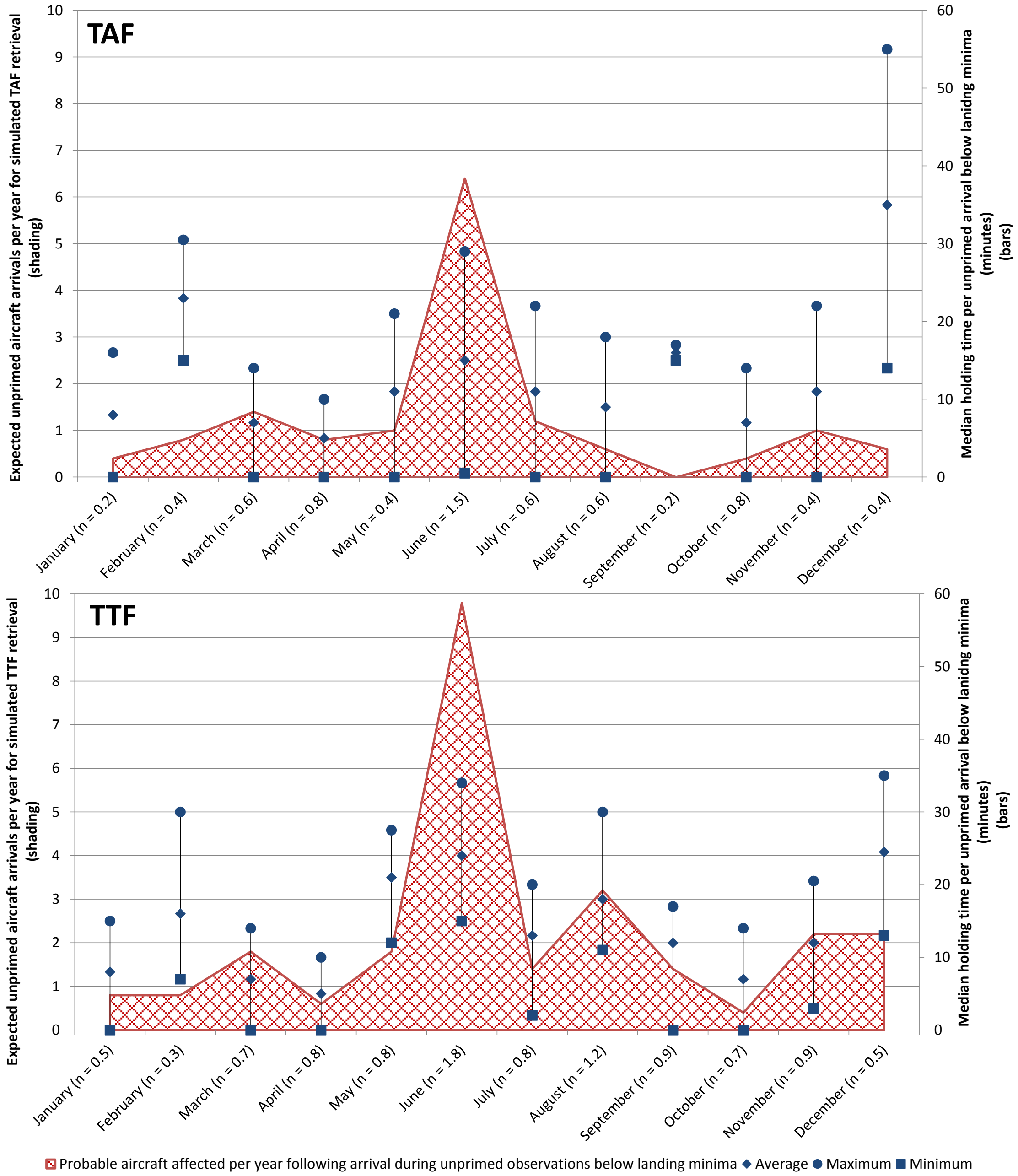
The shading on Figure 30 indicates expected number of aircraft arrivals per year in each month following retrieval of a TAF or TTF resulting in an unprimed observation at the time of arrival. The monthly horizontal axis labels also show the average number of episodes in each month per year, for example, June was simulated to have an average of 1.8 unprimed episodes for TTFs per year.

December had the highest median values for the average and maximum estimated unexpected holding time following retrieval of either TAF or TTF. Unprimed TAFs in December also had the largest variation between median values ranging from 14 to 55 minutes. However, the number of expected unprimed aircraft arrivals following simulated TAF retrieval December was relatively low, with one aircraft expected to arrive during an unprimed observation every 2 years.

June had the largest number of expected aircraft arrivals after the simulated retrieval of unprimed TAFs and TTFs. The median average unexpected holding time was calculated to be 14 minutes following unprimed TAF retrieval and 24 minutes following unprimed TTF retrieval.

The combination of probable aircraft affected (likelihood) and holding time (severity) can be used to provide an indication of the relative risk by month that unprimed observations have on aviation safety.

Figure 30: Estimated holding time for episodes with unprimed observations below landing minima and expected unprimed aircraft arrivals for each month, averaged for simulated TAF and TTF retrieval times zero to 2 hours prior to arrival 2009 to 2013



Time of the day by month

In the same way that Figure 25 and Figure 28 show the peak times of unprimed observations below the landing minima by hour of day and months by quadrants respectively, Figure 31 shows the peak periods by month and hour of day for sole retrieval of TAFs or TTFs. The coloured contours show the total time in hours per year, as labelled in the legend below. Note the graph is wrapped around at the end of the year to show continuity and data points are situated on depicted gridlines.

The most common time for unprimed TAFs and TTFs was between 1000 and 1100 in June, corresponding to the peaks in Figure 25 and Figure 28. Another common peak for both unprimed TAFs and TTFs was between 2100 and 2200 in November. As also shown above, TTFs had a longer duration of unprimed observations when compared with TAFs under the same simulated retrieval conditions.

Additional TTF periods of generally elevated unprimed observations were:

- June 0200 to 0300 and 0800 to 1200
- between 0600 and 0700 in May
- August 0500 to 0600 and 1000 to 1100.

There were no unprimed observations from February to May between 1900 and Midnight for TAFs or TTFs. Additionally, TAFs had no unprimed observations identified between 1200 and 1900 from August through to January in any year.

This graph highlights the seasonal and daily fluctuations of unprimed observations below the landing minima and shows areas that could be focused on for improved forecasting, in particular, 1000 to 1100 during June.

Figure 31: Hours active forecasts were available leading to unprimed observations below the landing minima per year, by hour of day and month, averaged for simulated TAF and TTF retrieval times between zero to 2 hours prior to arrival 2009 to 2013.

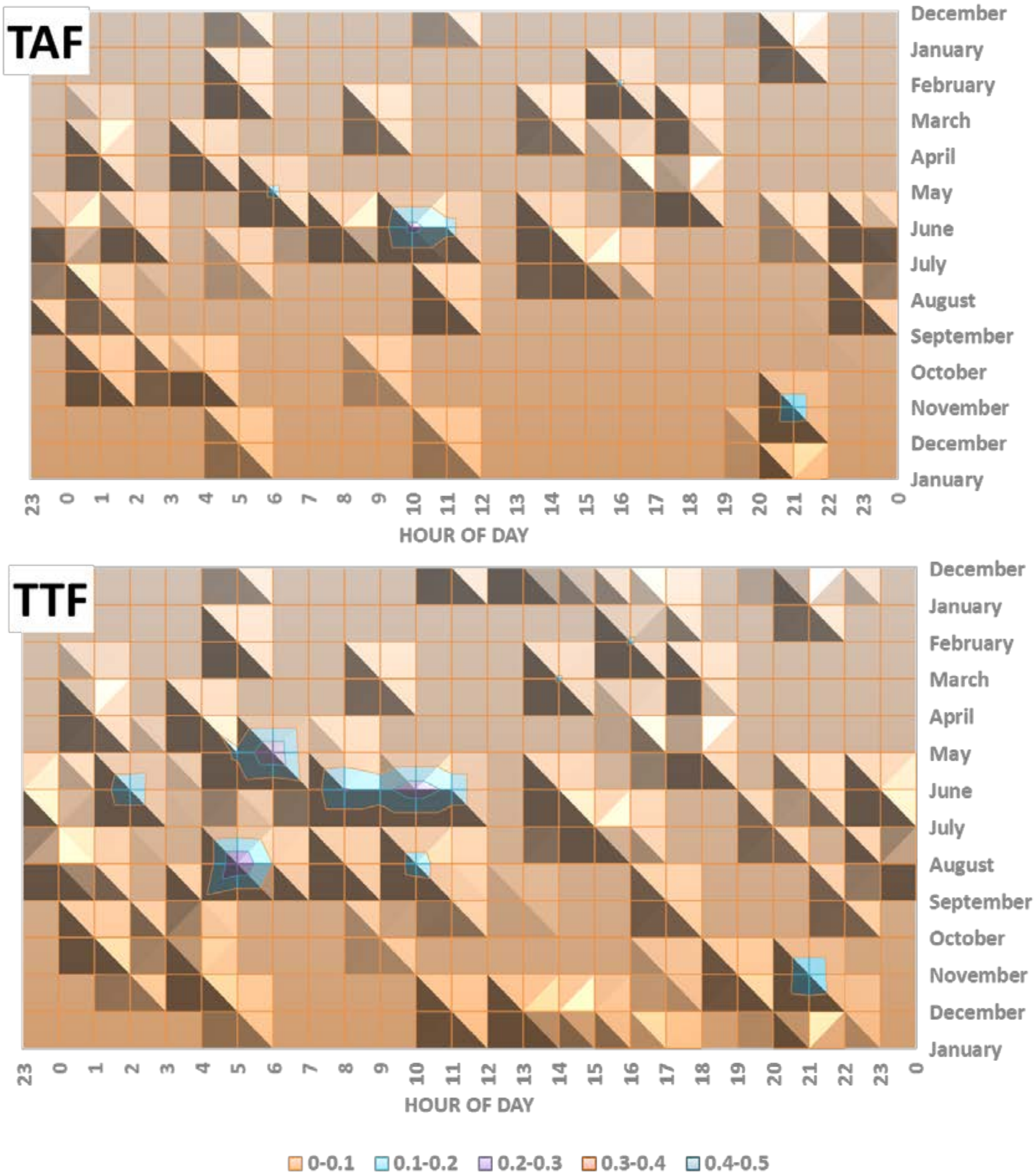


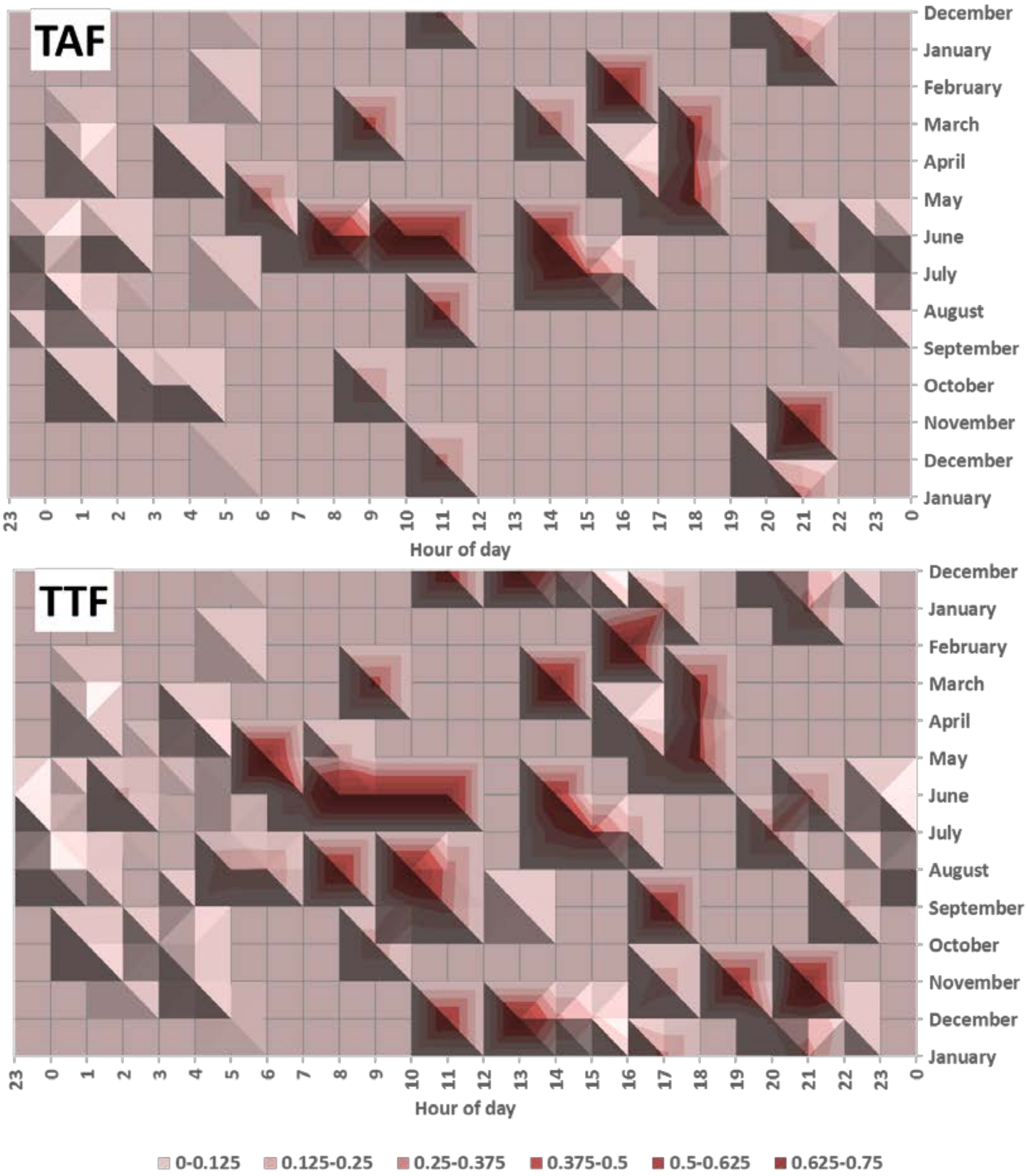
Figure 32 shows the expected aircraft arrivals during observations below the landing minima following unprimed TAF or TTF retrieval for each month and each hour of the day. It was seen in Figure 31 that the longest duration of unprimed observations were in the mornings in June for both TAFs and TTFs. This is also the case for the number of expected aircraft arrivals.

For TAFs and TTFs, elevated periods of expected unprimed aircraft arrivals were mornings in June, and between 2100 and 2200 in November, consistent with Figure 31.

Additional periods where elevated unprimed aircraft arrivals were expected include but are not limited to:

- unprimed TAFs and TTFs in June and July between 1400 and 1600
- unprimed TTFs in December between 1100 and 1400
- unprimed TAFs and TTFs in February between 1600 and 1700.

Figure 32: Expected aircraft arrivals per year, by hour of day and month during observations below the landing minima following averaged simulated retrieval of unprimed TAF and TTF zero to 2 hours prior to arrival 2009 to 2013.



Duration and effect of unprimed observations

Figure 33 shows the number of weather episodes with unprimed observations below the landing minima by the duration of all observed conditions below the landing minima. It shows the overall period of time that an aircraft could not land during episodes when there were both unprimed and no unprimed observations below the landing minima, combined for TAFs and TTFs. The distribution shows each weather episode by duration in contrast to median value statistics (as shown in Figure 24). This is important because a number of notable, but less common episodes are not reflected in these statistics alone.

Although many weather episodes had durations of half an hour or less (both unprimed and primed), there remained a number of weather episodes exceeding this duration. The cumulative percentage lines in Figure 33 show the proportion of weather episodes that contained unprimed observations (purple columns) to those when conditions were completely forecast (transparent columns) for each duration of the observed conditions below then landing minima.

When compared with episodes with no unprimed observations below the landing minima, there was a higher percentage of unprimed weather episodes between 1 and 45 minutes duration.

Around 32 per cent of unprimed episodes and 57 per cent of episodes without unprimed observations had a duration longer than 30 minutes. This indicates that although less common, longer durations of weather below the landing minima have occurred.

Figure 33: Duration of all observed conditions below the landing minima by number of weather episodes with unprimed observations for simulated TAF and TTF retrievals averaged between zero to 2 hours prior to arrival 2009 to 2013

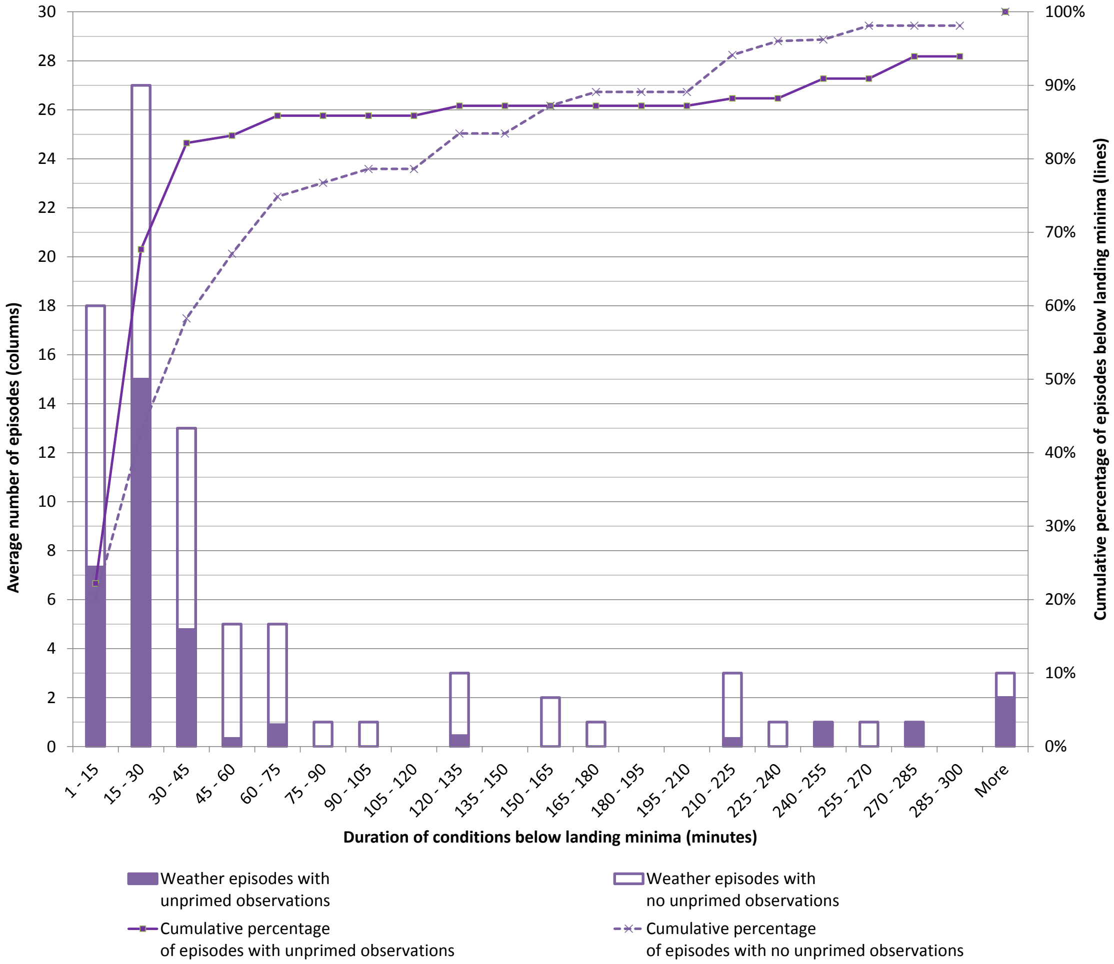


Figure 34 displays the calculated holding time durations on the horizontal axis, showing hours of unprimed observations per year. The height of the columns are proportional to the likelihood of arriving and having to hold for the time listed in the horizontal axis.

Each graph displays one of the four daily quadrants for TAFs and TTFs. The columns show the average, minimum and maximum calculated holding times. While the below text focuses on average holding time, the other columns can be reviewed to see the range from the best case scenario (minimum holding time) to the worst case scenario (maximum holding time). Lines indicate the cumulative percentage of time at or below the listed holding time (horizontal axis), increasing from left to right.

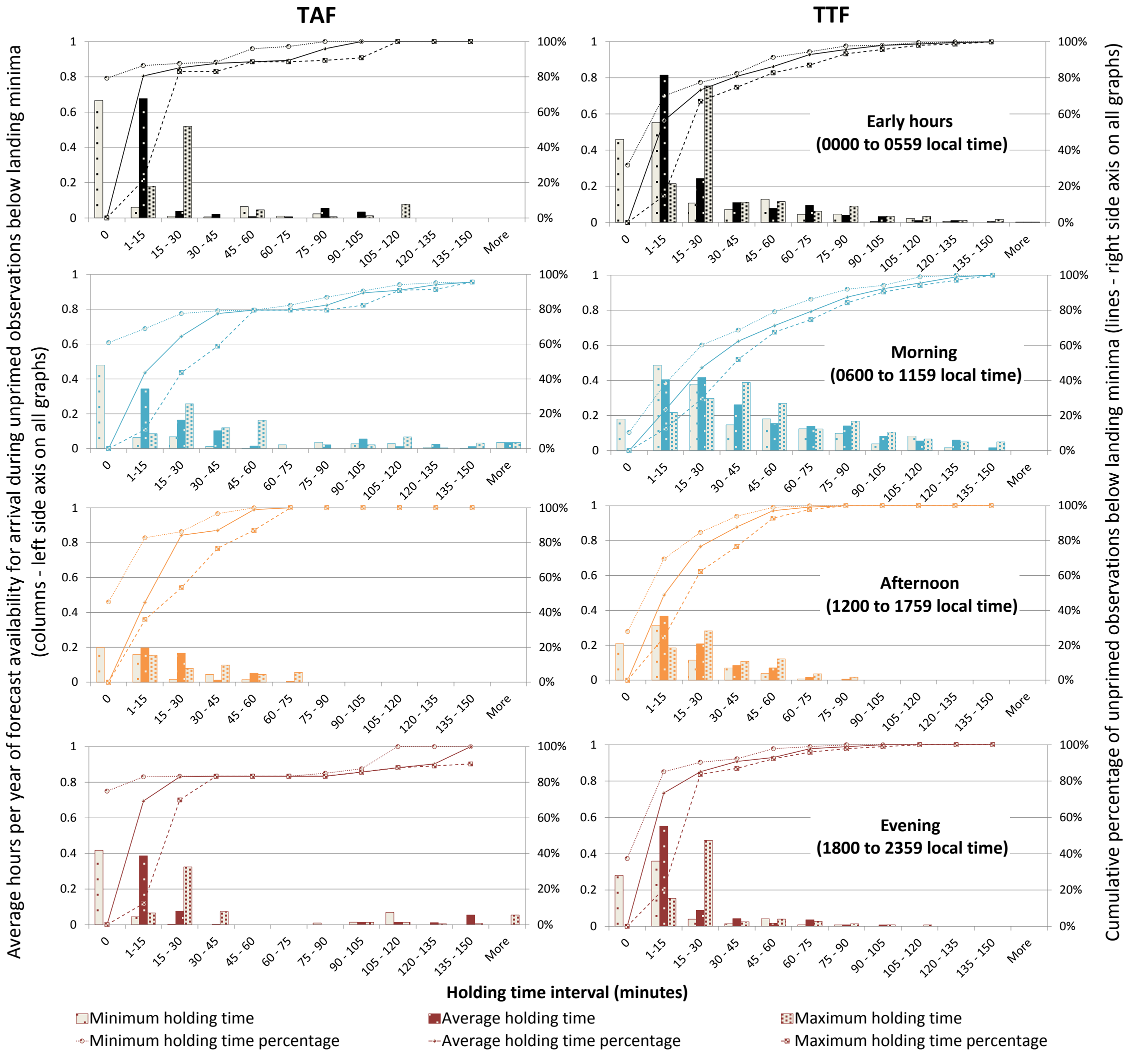
The charts second from the top (blue graphs second from the top in Figure 34), displaying morning holding times, show average holding times have a much longer range than at other times of the day, in particular for TTFs.

In the morning, 53 per cent of the duration of simulated unprimed TTF retrievals exceeded 30 minutes unexpected holding time. For simulated unprimed TAFs, this occurred for 36 per cent of unprimed observations.

In the early hours, 27 per cent of unprimed observations from TTFs and 15 per cent of unprimed observations from unprimed TAFs led to unexpected holding times exceeding 30 minutes.

The evening calculated holding times were generally quite short. Around seventy per cent of the evening holding times for both unprimed TAFs and unprimed TTFs were 15 minutes or less, although a small proportion of unprimed observations led to more than 1 hour of unexpected holding. The afternoon holding times were slightly more spread out, although none exceeded 90 minutes.

Figure 34: Distribution of hours per year of unprimed observations by average, minimum and maximum unexpected holding times, for simulated forecast retrieval times from zero to 2 hours prior to arrival 2009 to 2013



Forecast retrieval time comparisons

The sections above were based on averaged effects of simulated forecast retrievals between zero and 2 hours prior to arrival, averaged every 15 minutes. In this section, unprimed observations below the landing minima are analysed for every retrieval time (in 15 minute intervals) up to 150 minutes before arrival for both TAFs and TTFs (Figure 35), and also up to 12 hours for TAFs (Figure 36).

A key point of both figures is that, retrieving a forecast further before arrival will increase the likelihood of arrival during unprimed observations below the landing minima, regardless of the time of day. However, it is more critical for particular time periods than others.

Figure 35 shows the number of hours of unprimed observations per year as a percentage of all time (any type of observed weather), for each daily quadrant, for simulated retrieval of unprimed TAFs and TTFs. The time range (retrievals up to 150 minutes) was selected to compare both types of forecasts up to the continuously available validity period of the TTF.

For both TAFs and TTFs, there was a distinct difference in trend between the first half of the day (early hours and morning), and the second half of the day (afternoons and evenings), with the unprimed observations in the early hours and mornings being consistently more likely for all retrieval times.

When compared with TAFs, TTFs had generally more rapid decay in forecast predictions below the landing minima as the simulated retrieval time prior to arrival was increased. For the mornings (0600 to 1200), retrieving a TTF 60 minutes before arrival results in a 0.08 per cent chance of arriving during unprimed observations compared with 0.04 per cent for a TAF retrieval 60 minutes prior to arrival. This increases to 0.14 per cent chance if the TTF is retrieved 150 minutes before arrival, and only a 0.06 per cent chance for TAFs.

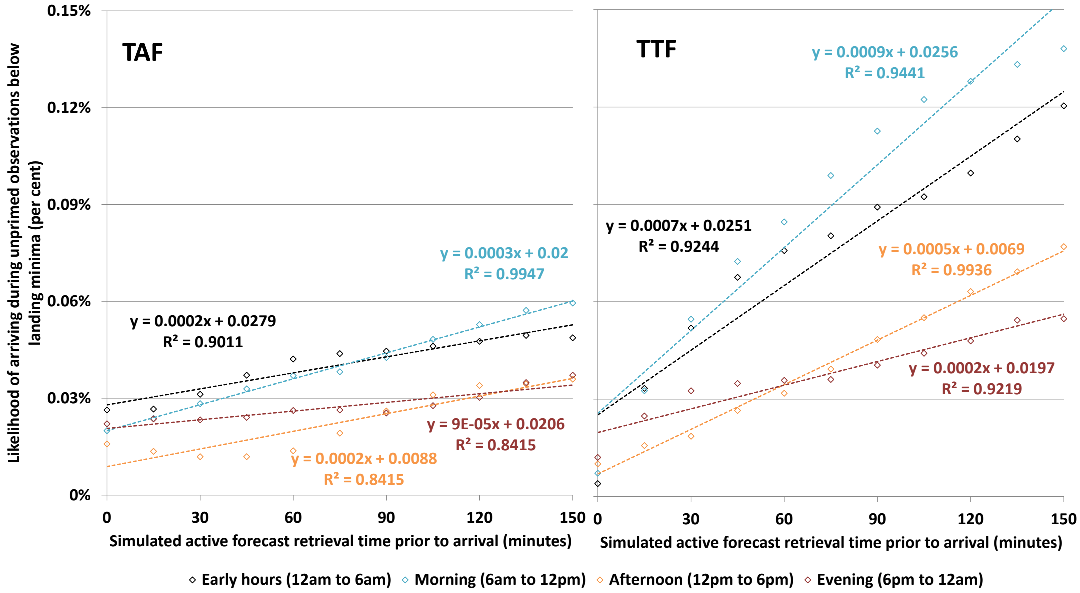
If a company flew a single aircraft to Adelaide every day of the year, and always arrived in the mornings, they are likely to arrive with an unprimed observation below the landing minima (derived from data in Figure 35 and Figure 36):

- about once every 7.4 years for TAFs and once every 3.3 years for TTFs if they are retrieved 1 hour before arrival
- about once every 4.6 years for TAFs and once every 2 years hours for TTFs if they are retrieved 2.5 hours before arrival
- about once every 3.9 years if they retrieve TAFs 4 hours before arrival
- about once every 22 months if they retrieve TAFs 9 hours before arrival
- about once every 16 months if they retrieve TAFs 12 hours before arrival.

The larger overall values and gradient in the early hours and morning are due to a larger number of observations below landing minima and the relative proportion of unprimed observations to the overall observations below landing minima. This probably relates to forecasting of low cloud, fog and mist.

From the perspective of operational decision making, this shows that in the early hours and morning, it is relatively more important that forecasts are retrieved at the latest possible time (before the point of no alternate) prior to arrival. However, in the afternoon and evening, the forecast retrieval time prior to arrival has less impact.

Figure 35: Likelihood of arriving during unprimed observations below landing minima for simulated TAF and TTF retrieval times prior to arrival (0 to 150 minutes) 2009 to 2013[50]

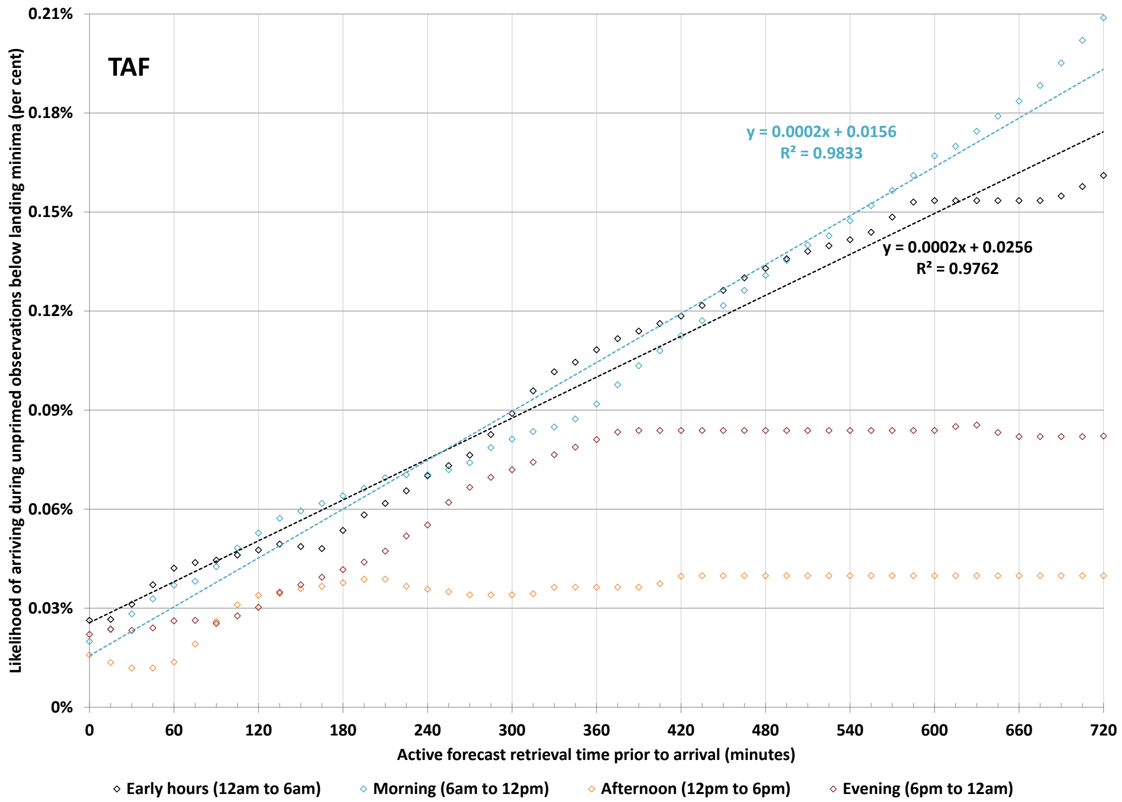


The increase in unprimed observations following simulated TAF retrieval appeared to plateau for some quadrants of the day as retrieval time prior to arrival increases (Figure 36). Unprimed observations in afternoons appear to asymptote (at 0.04 per cent of the time) for simulated TAF retrievals longer than 3 hours prior to arrival. Evenings also stabilised for TAF retrievals longer than 6 hours prior to arrival, with unprimed observations making up just over 0.08 per cent of the time.

Unprimed observations in the morning continued to increase at a steady rate of about 0.03 per cent for an increase of 1 hour in the simulated TAF retrieval time prior to arrival up to 12 hours.

50 R^2 shows the goodness of fit (percentage of variation explained) of the linear regression line to the scatter plot.

Figure 36: Likelihood of arriving during unprimed observations below landing minima for simulated TAF retrieval times prior to arrival (0 to 12 hours) 2009 to 2013



Analysis by time of day above (Figure 31) showed that between 1000 and 1200 was a particular common time for unprimed observations below the landing minima and coincided with peak aircraft arrivals at Adelaide. For 1000 to 1200 only, using the above example (a company flies to Adelaide once a day and arrives between 1000 and 1200), the chance of retrieving an unprimed observations below the landing minima is:

- about once every 2 years for TAFs and just over once every 14 months for TTFs if they are retrieved 1 hour before arrival
- about once every 15 months for TAFs and just under once every 14 months for TTFs if they are retrieved 2.5 hours before arrival
- about once every 13 months for TAFs if they are retrieved 4 or more hours before arrival.

Figure 37 and Figure 38 shows the percentage of unprimed observations as a proportion of all observations below the landing minima for arrival after retrieving a TAF or TTF between 0 and 150 minutes (Figure 37) and TAFs up to 12 hours (Figure 38) prior to arrival. In contrast to Figure 37 and Figure 36 which show the likelihood of arriving during an unprimed observation, these figures show the reliability of forecasts when observations are below the landing minima.

The early hours had the most rapid increase in the percentage of unprimed observations for both TAFs and TTFs as the duration of time between forecast retrieval and arrival became longer. The early hours quadrant proportion of unprimed observations increased 6.1 per cent for TAFs and 16.7 per cent for TTFs for each additional hour the forecast was retrieved prior to arrival. The percentage of unprimed observations in the morning had a more gradual rise than other quadrants of the day when simulated retrieval time was increased for both TAF and TTF.

The percentage of unprimed observations stabilised around 24 per cent in the afternoon and over 50 percent in evenings for simulated TAFs retrieved after 7 hours.

Seventy-two per cent of observations below the landing minima were unprimed for simulated TAF retrievals 12 hours prior to arrival in the early hours. Furthermore, 57 per cent of all observations below the landing minima in the morning were unprimed following TAF retrievals 12 hours prior.

Figure 37: Hours of unprimed observations as a percentage of all observations below the landing minima for simulated TAF and TTF retrieval times prior to arrival (0 to 150 minutes) 2009 to 2013[66]

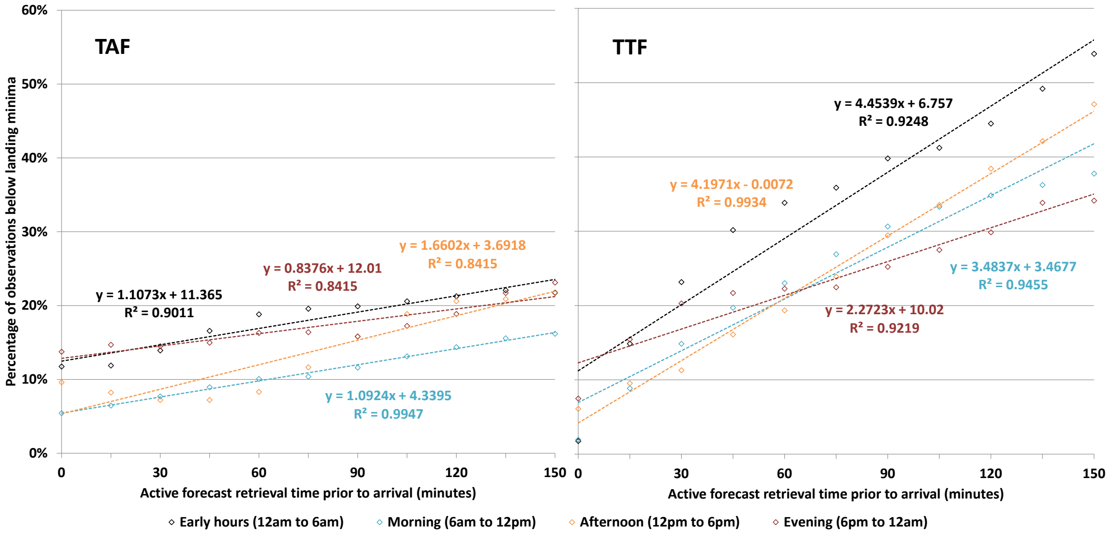


Figure 38: Hours of unprimed observations as a percentage of all observations below the landing minima for simulated TAF retrieval times prior to arrival (0 to 12 hours) 2009 to 2013

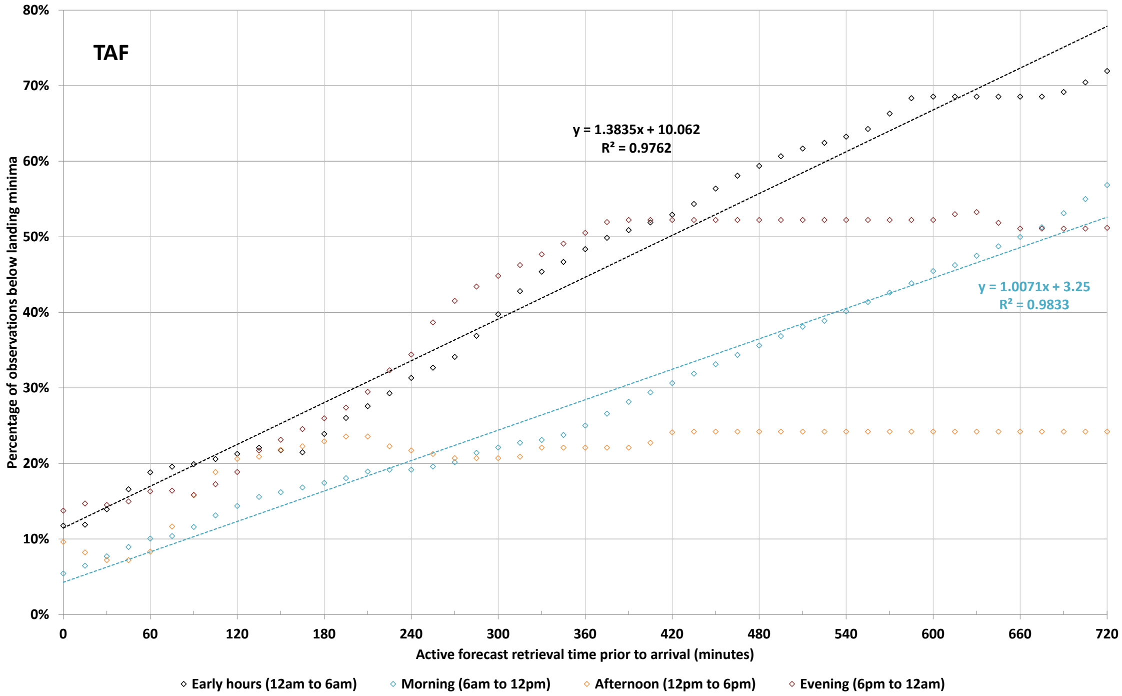


Figure 38 shows that for different times of day, the ability to predict when conditions will fall below the alternate minima is more difficult by varying degrees the longer prior to the observation. Similar characteristics existed between the order of unprimed TAFs and TTFs.

Figure 39 shows the variation in the holding time medians (calculated on groups of unprimed weather episodes) by quadrant of day for simulated TAF and TTF retrieval time prior to arrival with unprimed observations below the landing minima. Additionally, it shows the expected number of aircraft arrivals during unprimed observations per year for each retrieval time.

The median average unexpected holding time was low for all quadrants of the day for simulated TAF and TTF retrievals 0 to 6 hours prior to arrival. The longest unexpected holding time during this period was for TTF retrievals in the morning 75 minutes prior to arrival, with a median average holding time of 25 minutes.

Arrivals during unprimed observations from TTFs generally had a slightly higher median average holding time when compared to TAFs over the same time period.

Unexpected holding times for morning unprimed observations increased up to an average of 28 minutes for TAF retrievals 12 hours prior to arrival. This remained more stable for all other quadrants.

Expected unprimed aircraft arrivals in the morning increased considerably as the simulated retrieval time prior to arrival became longer. For TTFs, an increase from 11 expected unprimed arrivals up to 21 expected unprimed arrivals as simulated TTF retrieval times increased from 30 to 150 minutes prior to arrival. Comparing TAFs with TTFs, 21 expected unprimed aircraft arrivals was expected for simulated TAF retrievals more than 7 hours prior to arrival in the morning (as shown in blue shading in Figure 39). For TAFs, a substantial climb in the number of expected unprimed aircraft arrivals can be seen from less than 4 per year at the time of arrival, up to 34 per year if all TAF retrievals were performed 12 hours prior to arrival.

The number of expected arrivals during unprimed observations increased for other quadrants of the day to a smaller extent. As identified above (for example Figure 25 on page 64), more unprimed aircraft arrivals were expected if TTFs were solely used in lieu of TAFs.

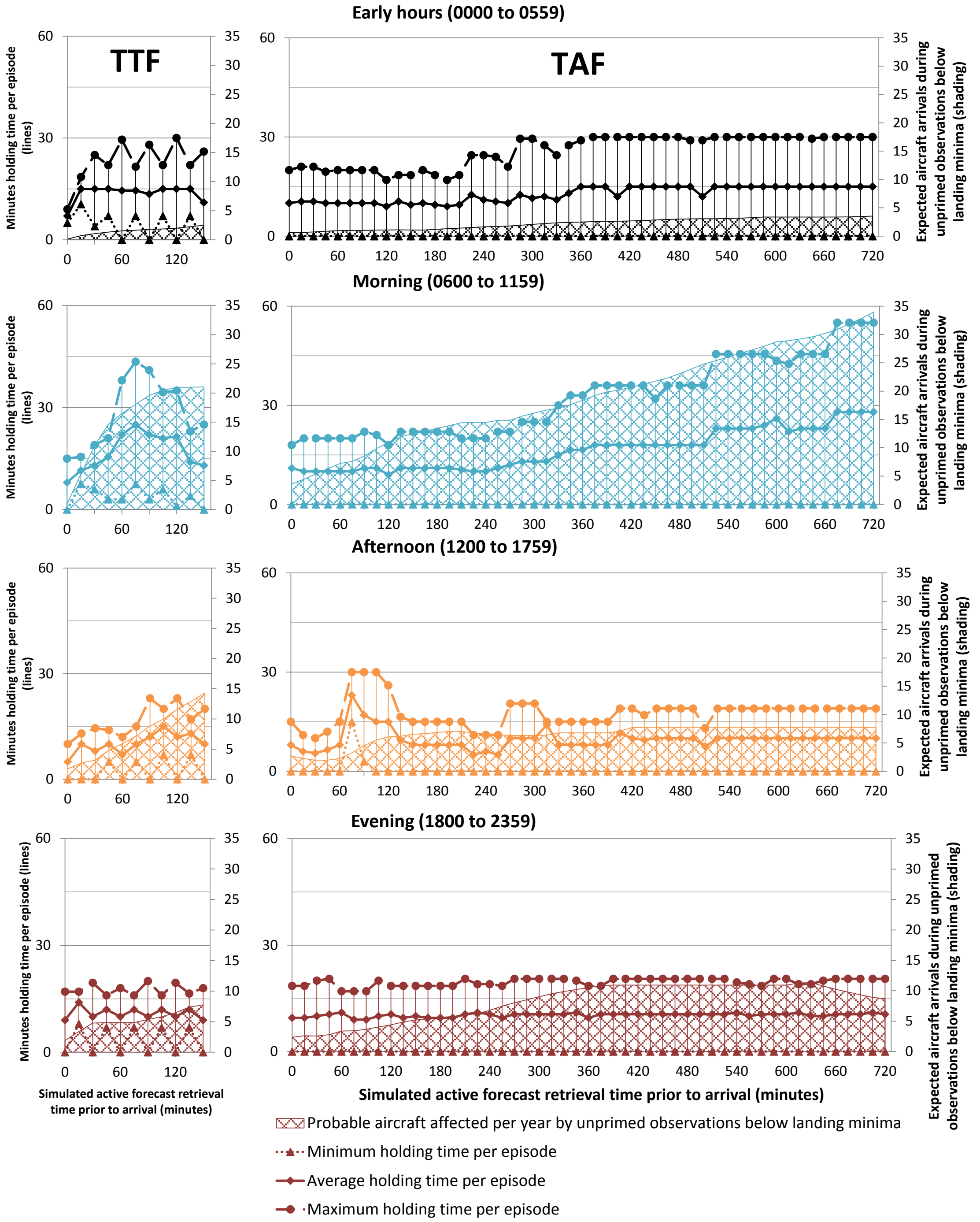
Expected aircraft arrivals plateaued in afternoons for unprimed TAFs at around 7 to 8 expected unprimed arrivals per year for simulated retrievals greater than 3 hours prior to arrival. For simulated TTF retrievals in the afternoon, 14 aircraft arrivals were expected during unprimed observations following retrievals 150 minutes prior to arrival, almost double the number of aircraft arrivals throughout the 12 hours of TAF simulations.

In the early hours, significantly fewer aircraft were expected to be affected by unprimed TAFs or TTFs over all retrieval time ranges, with a maximum of 3.5 arrivals per year for TAFs and 2.5 arrivals per year for TTFs. However, it is important to note that if an aircraft arrived during this period, there was a similar probability of arriving during unprimed observations below the landing minima as the morning (Figure 35 and Figure 36).

Based on the increased likelihood of unprimed observations below the landing minima, it is most important during the morning and early hours quadrants for pilots to retrieve a forecast as close as possible to their arrival into Adelaide. In the morning, an increase of 2.3 aircraft arrivals per year are expected for every hour prior to arrival that a TAF is retrieved.

Although median average holding time was low, it is important to note that a number of weather episodes had much larger holding times, particularly in the morning, as indicated in Figure 34. It is also important to note that following periods of degraded weather at Adelaide, a queue may have formed. The holding time will then also be affected by the maximum aircraft acceptance rate of the airport.

Figure 39: Median holding time (average, minimum and maximum) and expected aircraft arrivals during unprimed observations following simulated TAF and TTF[51] retrievals between zero and 12 hours prior to arrival 2009 to 2013



[51] Up to the maximum routine validity period of 150 minutes for TTFs (see Forecast validity periods and retrieval time prior to arrival on page 21).

Characteristics of unprimed observations at Adelaide Airport

Forecast timing characteristics

Unprimed observations below the landing minima were categorised by their chronological nature relative to the entire period below the landing minima, as shown in Figure 40. These are shown for unprimed episodes of simulated TAF and TTF retrievals unprimed observations averaged between zero and 2 hours prior to arrival. This is taken from the perspective of a pilot flying into an airport following the simulated retrieval at a fixed time prior to arrival, as shown in Figure 9.

Forecasts of observed conditions where predictions started late were the most common for both forecast types (about 2.9 episodes per year for TAFs and 5.6 episodes per year for TTFs). These were episodes that started in an unprimed state prior to becoming primed sometime after the first observations below the landing minima. This may be the result of either a new forecast being released or a time-based change existing within the original forecast. About seventy per cent of these starting late episodes were associated with thunderstorms and rain for both unprimed TAFs and TTFs. However, all other weather phenomena were also associated with episodes that started late. When considering unprimed fog or mist, episodes started in an unprimed state in 39 per cent of the time for TAFs and 58 per cent of the time for TTFs.

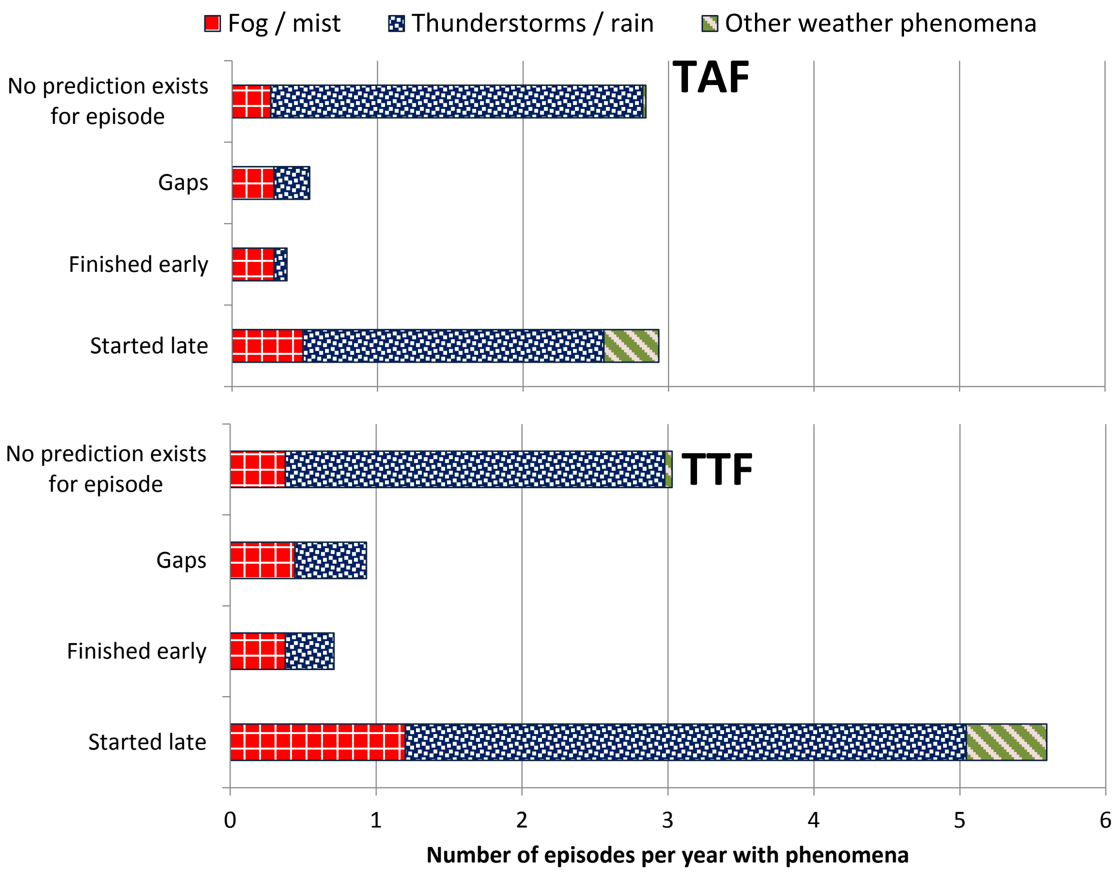
Almost all of the episodes with ‘other weather phenomena’ started in an unprimed state following simulated retrieval of both TAFs and TTFs 0 to 2 hours prior to arrival. These phenomena were episodes of drizzle, and combinations of rain, fog and mist.

Episodes where no prediction existed (Figure 40) refer to scenarios where all observations below the landing minima were unprimed for a nominated retrieval time prior to arrival. This applies even if that forecast predicted conditions below the alternate prior to or following, the observations below landing minima.

There were just under 3 episodes per year for TAFs and just over 3 episodes per year for TTFs where no forecast below the alternate minima was present for the duration of the observations below the landing minima. This made up half of all thunderstorms for unprimed TAFs and 37 per cent of thunderstorms for unprimed TTFs.

Gaps in the forecasting were the next most common type of unforecast observation for both types of forecast divided evenly between fog/mist and thunderstorms/rain. Forecasts finishing early were the least common reason, also divided evenly between fog/mist and thunderstorms/rain.

Figure 40: Number of episodes with unprimed observations below the landing minima by forecasting characteristic averaged for forecast retrieval times from 0 to 2 hours prior to arrival 2009 to 2013



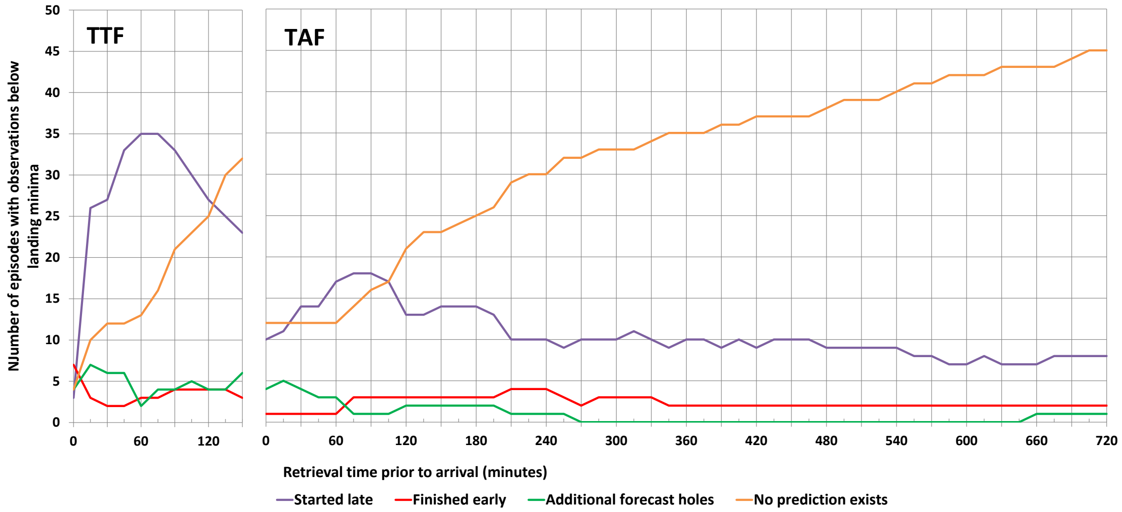
While Figure 40 shows the most common reasons for unprimed observations between zero and two hours before arrival Figure 41 shows the same reasons extending out to 12 hours for TAFs and 150 minutes for TTFs (the TTF routinely available validity period) Figure 41 shows that while it was more common for episodes to start in an unprimed state (started late) than having no prediction at all in the first two hours, after about two hours before arrival, the number of episodes below the landing minima that had no predictions increases (to 9 per year 12 hours before arrival for TAFs and 6 per year for TTFs for 150 minutes before arrival).

Episodes ending with unprimed observations (finished early) were relatively stable for TAFs (average 1 episode every 2 years) and TTFs (average 3 episodes every 4 years). Episodes with unprimed observations in between primed observations (forecast holes) were negligible for retrieval times after 4 hours for TAFs, and average around 1 per year for TTFs.

The peak in episodes starting late was around 60 to 90 minutes before arrival for unprimed TAFs at 7 episodes every 2 years and twice that number for TTFs at 7 episodes per year. TTF episodes starting late increased considerably from simulated retrievals at the time of arrival to 15 minutes prior to arrival. This is mostly accounted for in the release of primed TTFs (following an unprimed period) attached to a SPECI reporting the start of conditions below the landing minima (also discussed in *Systemic response to unprimed forecasts* below).

More generally, the peaks in episodes starting with unprimed observations are probably related to systemic reaction to unprimed forecasts when conditions appear to be degrading below the observed alternate minima. This is discussed below.

Figure 41: Number of episodes with unprimed observations below the landing minima (for each retrieval time prior to arrival) by forecasting characteristic 2009 to 2013 (Note: Sum of characteristics is greater the total number of episodes due to multiple categories applying to some episodes.)



Systemic response to unprimed forecasts

Forecasts being released in response to an anticipated or actual unprimed observation were common for TAFs and TTFs at Adelaide. Distinct differences were observed between the timing of these responses for TAFs and TTFs relative to the start of the expected or observed unprimed state.

Figure 42 provides a summary of the forecast release behaviour immediately prior to or following the first observation below the landing minima (start time) of each episode. To evaluate this, four scenarios were identified:

- First observation below the landing minima covered by a primed forecast, with the previous forecast also being primed: These scenarios are not shown in Figure 42 due to no operational change from the previous forecast occurring.
- Predictive system recovery: First observation below landing minima covered by a primed forecast, however, the forecast released immediately prior was unprimed for this time. These are scenarios where the system has responded prior to the first observation – labelled 'Predictive system recovery' in Figure 42. Including the first observation below landing minima, having 16 episodes for TAFs and 23 episodes for TTFs.
- Reactive system recovery: A forecast is released in response to the first observation below landing minima being unprimed (10 TAF episodes – median reaction time 35 minutes, and 3 TTF episodes – median reaction time 7 minutes).
- Weather improved prior to system recovery: Observations below landing minima remain unprimed for the duration of the episode (12 TAF episodes – median duration 18.5 minutes, and 4 TTF episodes – median duration 8 minutes).

Episodes with predictive system recovery prior to the first observation below landing minima (left side of Figure 42) were almost exclusively exhibited by TAFs at Adelaide. It is important to note that if the forecast would have been retrieved prior to these times in each category, they would have resulted in an unprimed arrival. Most TAFs in this scenario were labelled as 'amended', and were released more than 1 hour prior to the first observation below landing minima.

Reactive system recovery was also mainly related to TAFs following an unprimed observation below landing minima. Nine out of 10 of these scenarios related to an amended TAF release, and one related to a forecast timing change to recover the situation. The median reaction time for

TAFs was 35 minutes. In contrast, very few TTFs were unprimed past the first observation below landing minima, with a median reaction time of 7 minutes for these 3 episodes.

Due to the Australian Aeronautical Information Publication stipulating that TTFs be used in lieu of TAFs if available and valid,[52] the update requirements for TAFs are reduced, [53] which is likely to affect these results.

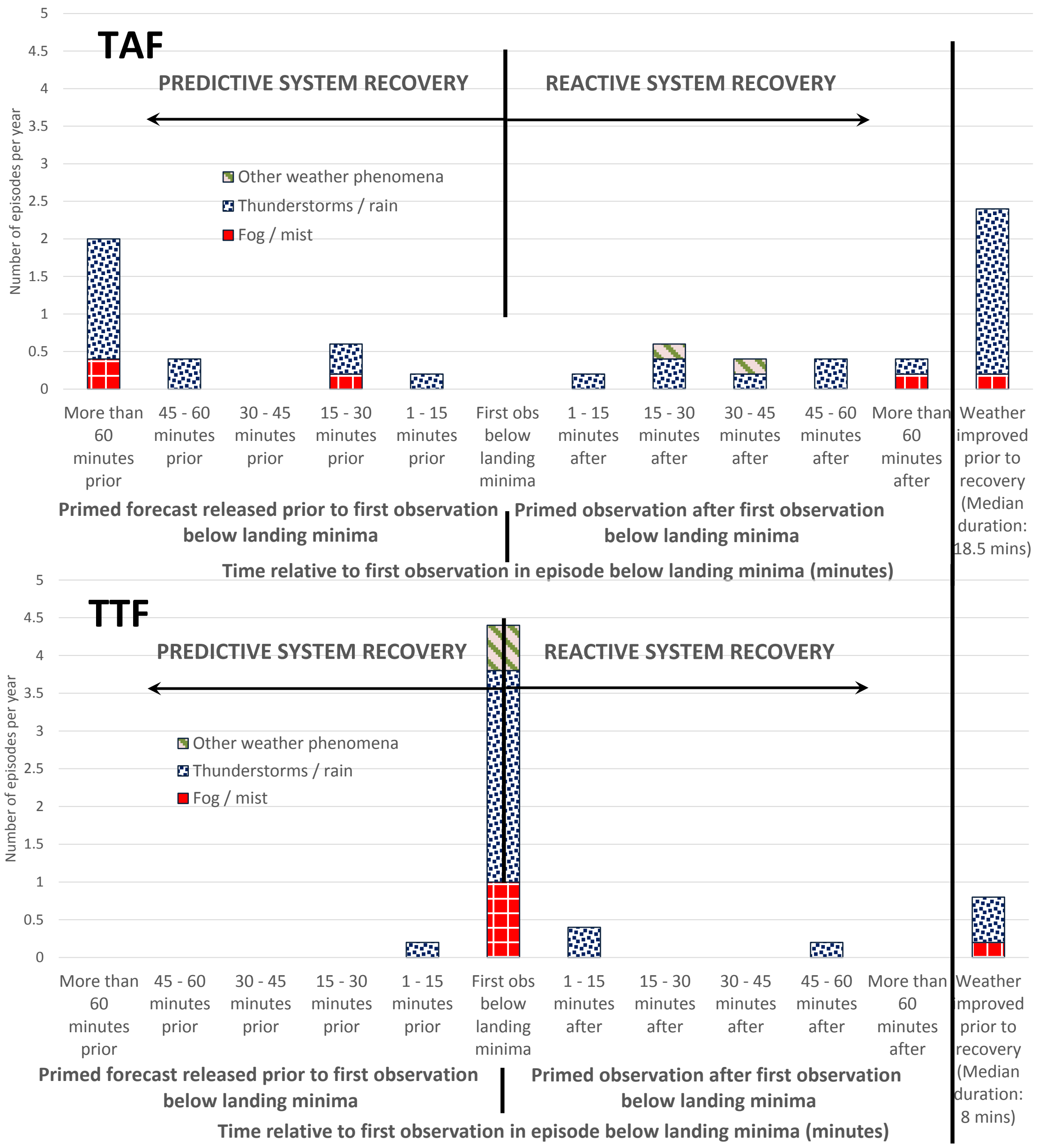
The duration of unprimed episodes where the observations below the landing minima were never covered by a primed forecast generally fell within the median reaction times for both TAFs and TTFs. This supports that a system response probably would have occurred had these episodes been of longer duration, and it is expected that the duration of these episodes was not long enough for the system to react.

Episodes where the system reaction has occurred at the first observation below landing minima indicate where a primed forecast was released at the time of the first observation below landing minima. This scenario was only observed for TTFs at Adelaide, with these TTFs being released attached to the first SPECI reporting observations below landing minima. This also made up the majority of episodes for unprimed TTFs being recovered. As for cases described to the left of the time of first observation below landing minima, a forecast retrieved immediately prior to this time would be unprimed. This is shown by the steep rise in episodes 'starting late' for TTF retrievals 15 minutes prior to arrival in Figure 41, effectively shifting the values of Figure 42 one increment to the right, specifically the 4.5 episodes per year for TTFs.

Note that for forecast retrieval at the time of arrival there were fewer episodes involving unprimed TTFs (17 out of 87) for simulated retrieval at the time of arrival compared with TAFs (27 out of 86). With considerably more unprimed episodes for TTFs than TAFs after this time. This can be explained by the relatively large number of system recoveries for TTFs attached to the first SPECI below the landing minima of an episode.

[52] Australian Aeronautical Information Publication GEN 3.5 - 6 3.6.3 dated 02 March 2017, Airservices Australia.
[53] As advised from the Bureau of Meteorology.

Figure 42: Primed forecast release times relative to first observation below landing minima in each weather episode (Predictive system recovery and reactive system recovery) and unprimed episodes with no recovery by observed weather phenomena, Adelaide Airport 2009 to 2013



Landing and alternate minima criteria for primed and unprimed observations

The red columns in Figure 43 show the hours per year the observed weather at Adelaide was below each of the five landing minima criteria (both unprimed (dark red) and primed (light red)). Referring to Figure 6 on page 26, these are the same as the categories ‘Miss’ for unprimed and two categories ‘Hit (H1)’ and ‘System buffer’ (B1) for primed. For the visibility and ceiling criteria, it also shows observations above the landing minima but below the alternate minima that were unprimed (dark blue) and primed (light blue), again from Figure 6, this equates to ‘System buffer (B2)’ for unprimed and ‘Hit (H2)’ and ‘Partial Hit (PH)’ for primed. A breakdown of the totals of each of these categories is shown in Figure 18 on page 55.

When compared with TAFs, TTFs had higher proportion of unprimed observations below the landing minima for each landing minima criteria. In contrast, the proportion of unprimed visibility and ceiling for TAFs and TTFs between the landing and alternate minima was relatively similar. These are scenarios where visibility and cloud base fell below the alternate minima, however, was not forecast to do so, and indicates cases where the safety buffer between the landing and alternate minima has been used. There were more observations between the landing and alternate minima (both primed and unprimed) than below the landing minima.

The percentage of unprimed thunderstorms, visibility and ceiling below the landing minima were similar for TTFs ranging from 21 to 23 per cent. In contrast, TAFs had much lower percentages at 11 and 15 per cent for visibility and thunderstorms respectively. Unprimed TAF ceiling forecasts had a much lower percentage than other landing minima criteria (except for TAF crosswinds), with 1 in 20 minutes of ceiling being unprimed.

In addition, 21 per cent of observations were unprimed for visibility in TTFs, but only 8 per cent were unprimed for ceiling. As the existence of thunderstorms is the only criteria for both landing and alternate minima, and because the crosswind and tailwind had the same thresholds applied for both the alternate and landing minima, these criteria not have did not have any observations between the alternate and landing minima.

Figure 43: Hours per year for observed criteria below landing minima and below alternate minima, primed and unprimed for simulated TAF and TTF retrieval times 0 to 2 hours prior to arrival

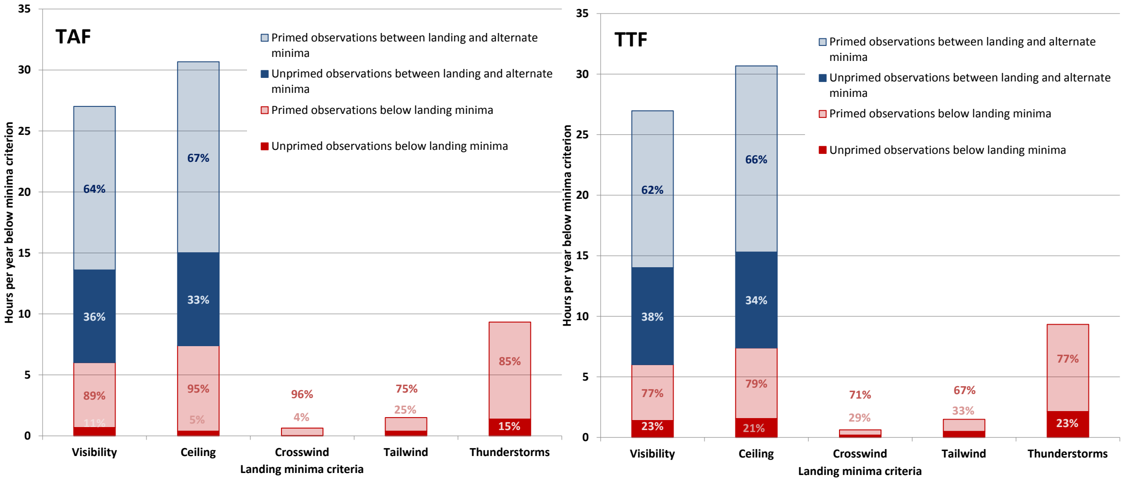
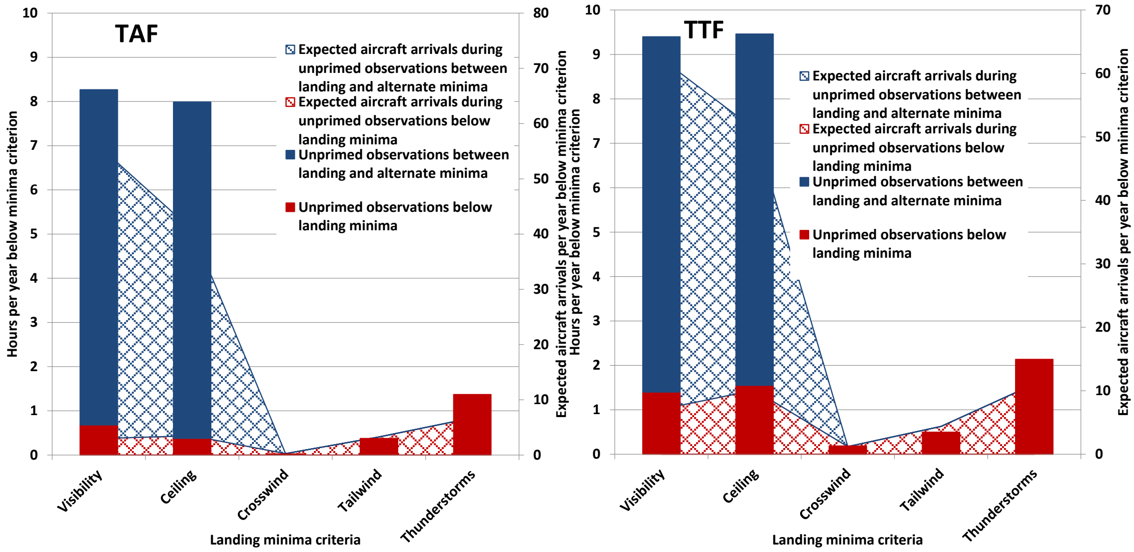


Figure 44 shows only unprimed observations along with the number of expected aircraft arrivals during these times each year for TAFs and TTFs. This shows the considerably larger unprimed periods between the landing and alternate minima for visibility and ceiling.

The two largest differences between TAFs and TTFs for unprimed conditions was ceiling and thunderstorms. Unprimed ceiling below the landing minima was observed around 90 minutes per year for TTFs, and 22 minutes per year for TAFs with 10 and 3.5 expected aircraft arrivals respectively during these times. About 11 aircraft were expected to arrive during unprimed thunderstorms for simulated TTF retrievals, and 6 aircraft for simulated TAF retrievals.

Figure 44: Hours per year for unprimed observed criteria below landing minima and below alternate minima, average simulation of TAF and TTF retrievals 0 to 2 hours prior to arrival. Hatched area shows aircraft affected/encountering the unprimed conditions.



Unprimed weather phenomena

Figure 45 shows the total duration in hours per year and number of expected aircraft arrivals per year during unprimed observations below the landing minima by the main weather phenomena groupings at Adelaide.[54] Consistent with established trends for Adelaide, unprimed TTFs had higher numbers in each weather phenomena category for unprimed observations below landing minima and also unprimed aircraft arrivals.

Unprimed thunderstorms and rain were had the largest number of expected aircraft arrivals for both forecast groups, with around 15 aircraft expected to arrive each year during thunderstorms and/or rain following retrieval of an unprimed TTF. For unprimed TAFs this number was about 10 expected aircraft arrivals per year. Note that this includes cases where only rain is reported without thunderstorms, hence the expected numbers being higher than thunderstorms alone, as shown in Figure 44 above.

Fog / mist / low cloud was the next most common phenomena group associated with unprimed observations for both TAFs and TTFs. Low cloud was combined with fog and mist as these were all identified as being associated with different stages of fog episodes for Adelaide. Just under 11 aircraft per year were expected to arrive during unprimed observations and this phenomena group for TTFs.

The largest difference between TAFs and TTFS was unprimed observations during fog, mist and low cloud, despite having fewer numbers than thunderstorms overall. Almost five additional aircraft arrivals were expected each year for simulated TTF retrievals compared with TAF retrievals 0 to 2 hours prior to arrival, making up around 6.5 hours per year.

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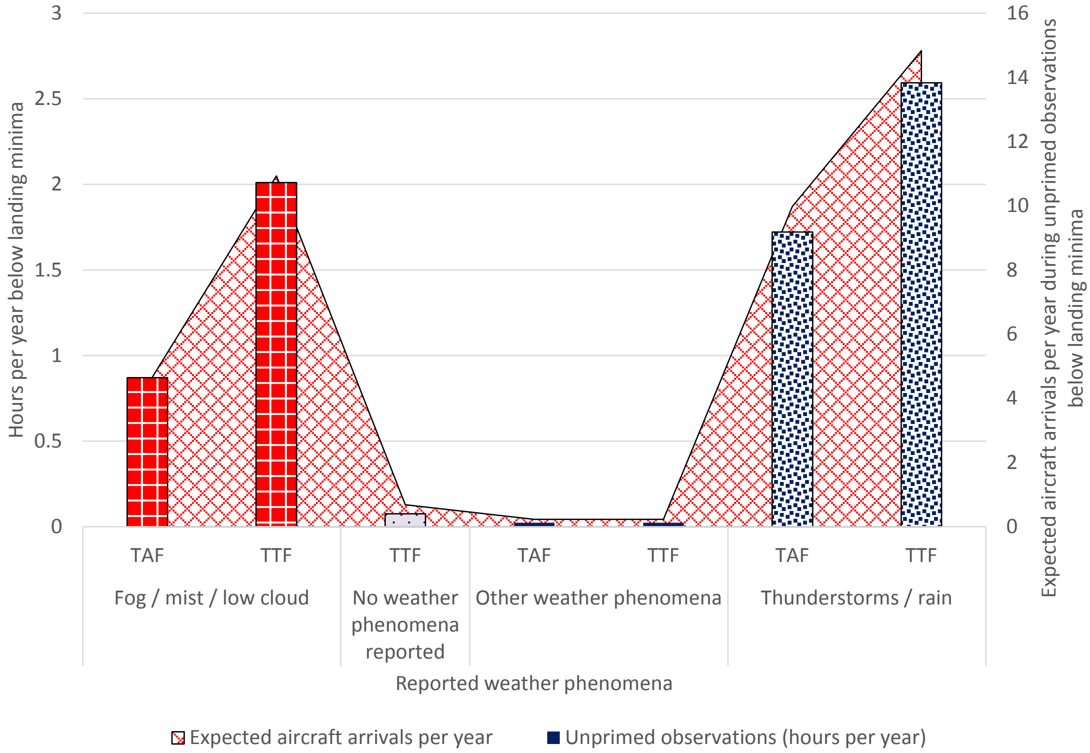
54 The relationship between these common groupings and landing minima criteria is shown in Figure 15 on page 46. Note that all fog, mist and low cloud were associated with visibility, ceiling (and tailwind) below the landing minima (primed and unprimed). No phenomena was typically associated with low cloud.

Figure 45: Hours per year and number of expected aircraft arrivals per year for unprimed weather phenomena, averaged for simulated TAF and TTF retrievals 0 to 2 hours prior to arrival



The distribution of weather phenomena associated with unprimed observations (collectively shown in Figure 45) is shown by hour (Figure 46) and month (Figure 47) below. The columns in each graph correspond to the number of unprimed observations (in hours per year), split by reported weather phenomena. This data is also shown for time of day in Figure 25 (solid columns) on page 64.

The dashed lines in Figure 46 and Figure 47 show the percentage of unprimed observations compared with all observations below landing minima where each phenomena were reported. This shows the same data as presented in Figure 26, but divided between each reported phenomena.

Thunderstorms had the least reliable percentages of unprimed observations for both TAFs and TTFs between 0300 and 0400, and between 0900 and 1000.

Unprimed observations were associated with unprimed fog, mist and low cloud in the early hours and morning. As identified in Figure 45, reported fog/mist and low cloud were associated with the largest differences between TAFs and TTFs, which is particularly evident at 0500 to 0700 and 0800 to 1100. Differences between unprimed observations during thunderstorms and rain were more evenly distributed between TAFs and TTFs by hour of day.

Differences between unprimed observations from TAFs and TTFs were the largest in the months of August, June and May driven by fog, mist and low cloud (Figure 47). June was also the least reliable time for predicting thunderstorms for both TAFs and TTFs, as shown by the blue dashed line.

Figure 46: Weather phenomena reported during unprimed observations below landing minima by hour of the day for simulated forecast retrievals average 0 to 2 hours prior to arrival, 2009 to 2013

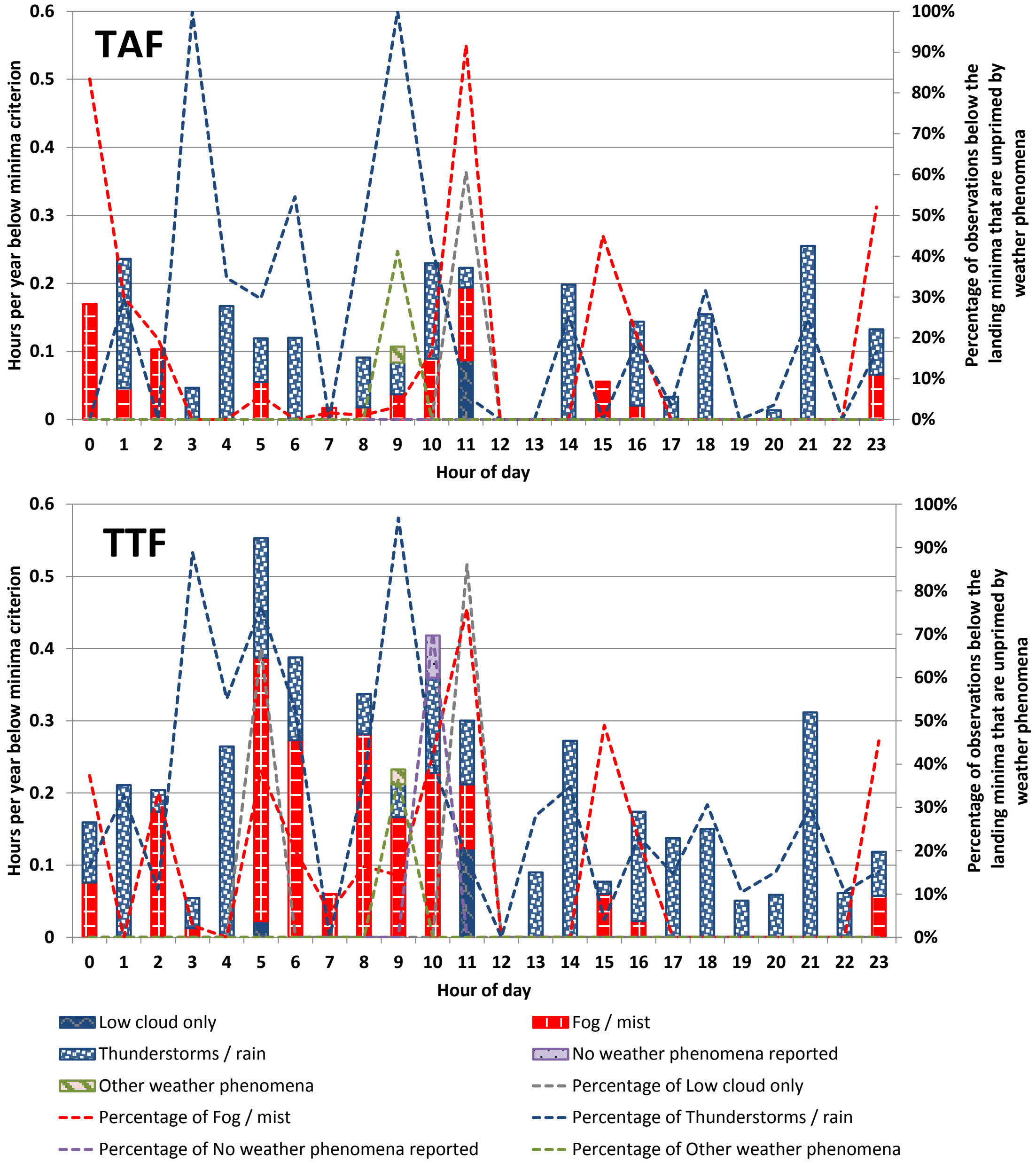
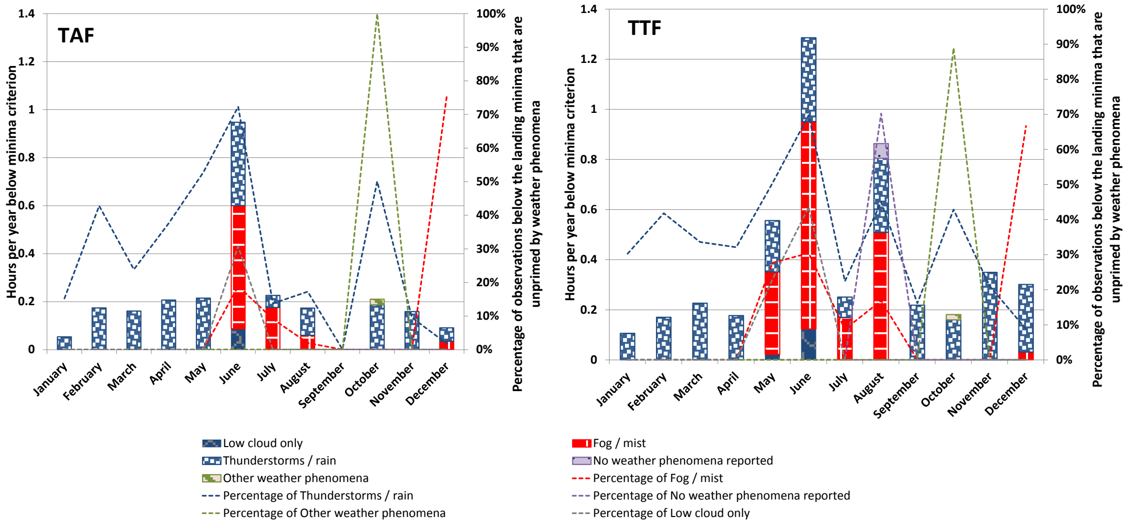


Figure 47: Weather phenomena reported during unprimed observations below landing minima by month of the year for simulated forecast retrievals average 0 to 2 hours prior to arrival, 2009 to 2013



Retrieval time

Unprimed minima criteria

Figure 48 shows the hours each year of unprimed observations for each minima criteria for up to 150 minutes before arrival for TTFs and 12 hours before arrival for TAFs. Figure 49 shows the percent of all observations below the landing minima that were unprimed for each minima criterion.

Increasing the retrieval time prior to arrival has the greatest effect on the reliability of forecasts relating to thunderstorms, visibility below the landing minimum, followed by ceiling below the landing minimum. The prediction of low visibility and thunderstorms have a similar percentage of observations below the landing minima that are unprimed for simulated TAF retrievals up to 6 hours prior to arrival (Figure 49). At 6 hours prior to arrival, the reliability of thunderstorm predictions stabilises, whereas both visibility and ceiling continue to rise.

TTFs had a much more rapid degradation in unprimed observations at simulated retrieval time prior to arrival increased.

Figure 48: Hours per year of unprimed observations below the landing minima (at the time of arrival) for each minima criterion by forecast retrieval times between zero and 6 hours prior to arrival

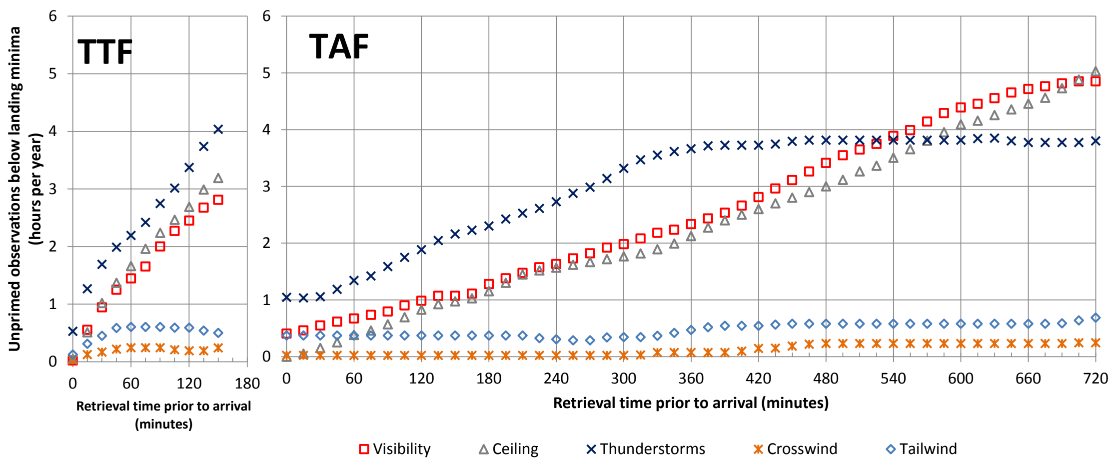
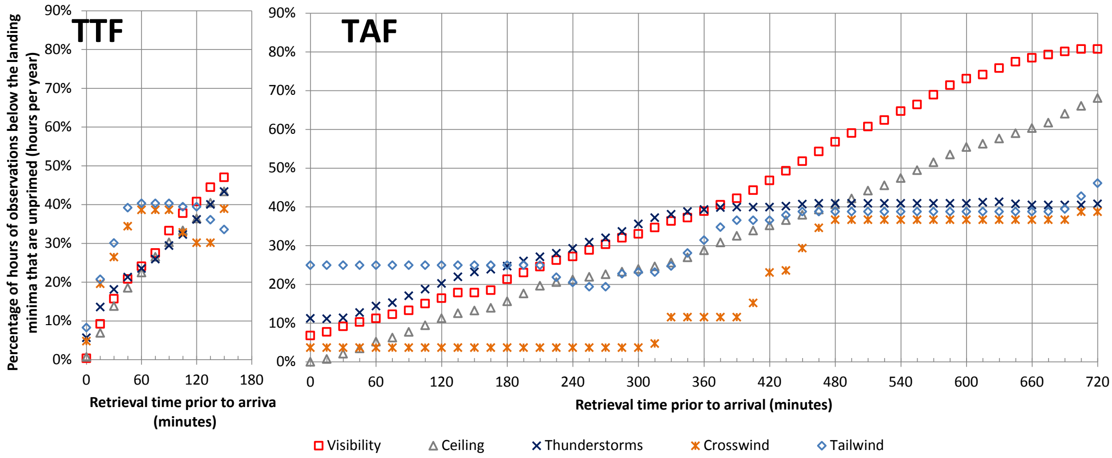


Figure 49: Percentage of observations below the landing minima (at the time of arrival) that were unprimed for each minima criterion by forecast retrieval times between zero and 6 hours prior to arrival



Unprimed weather phenomena

Figure 50 shows the hours each year of unprimed observations for each weather phenomena for up to 150 minutes before arrival for TTFs and 12 hours before arrival for TAFs. Figure 51 shows the percent of all observations below the landing minima that were unprimed for each weather phenomena.

Fog and mist steadily increased in the hours of unprimed observation up to 12 hours prior to arrival. Fog and mist reliability was very close to no unprimed observations at the time of the arrival.

TTFs had a much more rapid degradation in unprimed observations associated with fog/mist and thunderstorms/rain as simulated retrieval time prior to arrival increased.

Figure 50: Hours per year of unprimed observations below the landing minima (at the time of arrival) for weather phenomena by forecast retrieval times between zero and 6 hours prior to arrival

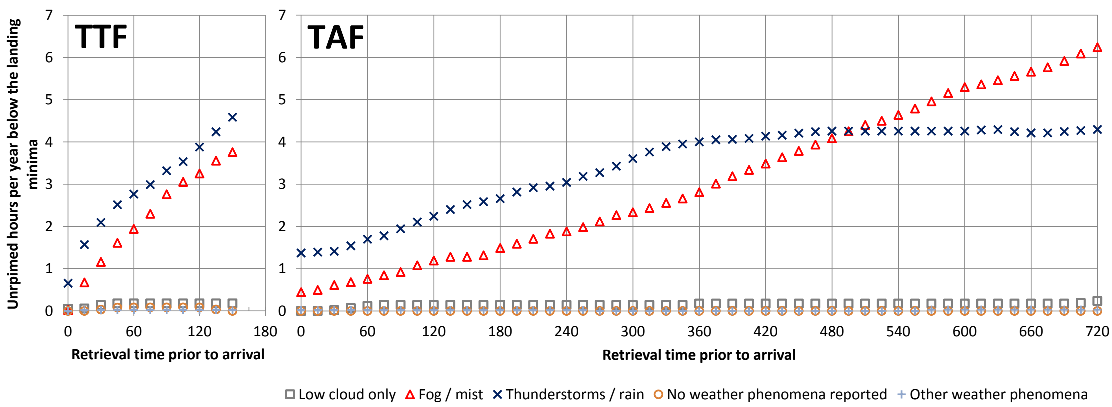
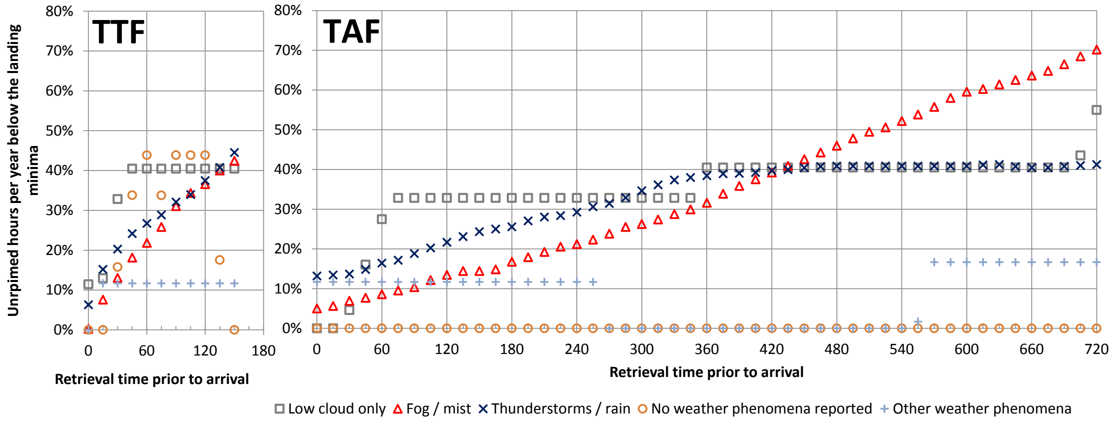


Figure 51: Percentage of observations below the landing minima (at the time of arrival) that were unprimed for reported weather phenomena by forecast retrieval times between zero and 6 hours prior to arrival



The effect of using thresholds below the alternate minima

Holistic operational effects of using different forecast minima thresholds

Figure 52 shows the overall effect of different minima thresholds (as labelled in the horizontal axis) if they were used for operational decision making instead of the alternate minima for the number of probable aircraft affected per year, and the forecast availability compared to all time between 2009 and 2013.

The horizontal axis values were calculated using a scaling process to standardise all values for different approaches and minima criteria into a single ‘worst-case’ value for each forecast segment. This allowed the calculation of the number and duration of observations reported below the landing minima in each ‘worst-case’ landing minima group, and also the calculation of probable aircraft affected. This involved setting the landing minima to a value of ‘1’ and the alternate minima to a value of ‘2’ and scaling the data to fit within this constraint.

This value was calculated according to the following process:

- For each TAF, select the lowest of the following values:
  - thunderstorms and maximum crosswind forecast were considered at the landing minima and given a value of 1
  - visibility and ceiling were calculated according to the following equation:

$$x_{Scaled_{Vis,Ceil}} = 1 + \frac{(x_{TAF_{Vis,Ceil}} - L_{Vis,ceil})}{(A_{Vis,Ceil} - L_{Vis,Ceil})}$$

  Where:

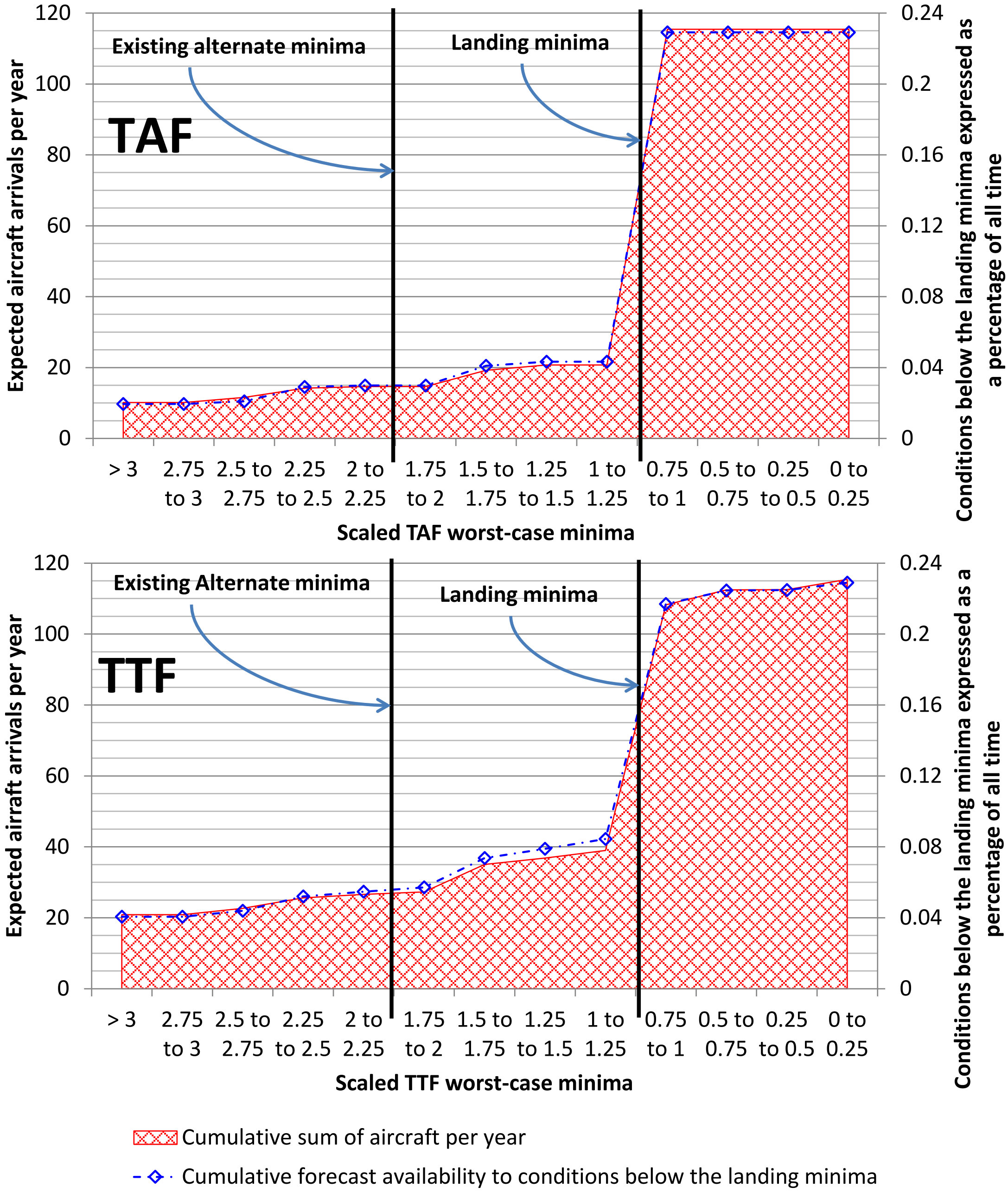
  - $x_{Scaled_{Vis,Ceil}}$ represents the final scaled value of forecast ceiling or visibility relative to the landing and alternate minima
  - $x_{TAF_{Vis,Ceil}}$ represents the original value of forecast ceiling or visibility
  - $L_{Vis,ceil}$ represents the landing ceiling or visibility
  - $A_{Vis,Ceil}$ represents the alternate ceiling or visibility
- Aggregate all parameters grouped by the selected and scaled ‘worst-case’ minima values. For example, all forecast values between 2 and 2.25 were combined together.
- Calculate the proportion of this group falling below the landing minima and determine characteristics such as the total relative time and the probable number of aircraft affected.
- The scaling process results in some values below zero. These values were rounded to zero and were present due to the focus of the current analysis being between the landing and alternate minima.

Data to the left of the line marked 'Alternate minima' in Figure 52 shows values for forecasts predicting conditions above the alternate minima, which were subsequently reported below the landing minima (unprimed).

This shows cumulative percentage by the 'worst-case' TAF/TTF minima value (accumulated from left to right on the horizontal axis) of total time that forecasts were available, with reported observations below the landing minima on arrival (represented by the blue dashed line, and shown on the right hand side vertical axis).

Figure 52 shows the transition from forecast conditions above the alternate minima (on the left), between the alternate and landing minima (in the middle), to a forecast below the landing minima.

Figure 52: Probable aircraft affected per year and overall percentage of forecast availability to observations below the landing minima by scaled TAF worst-case minima value for forecast retrievals zero to 2 hours prior to arrival 2009 to 2013



The data point labelled '2 to 2.25' located immediately left of the 'Alternate minima' line of Figure 52 represents the cumulative sum of all available forecasts predicting conditions above the alternate minima where observations are reported below the landing minima upon arrival. This can be seen in Figure 18, which shows the percentage of these conditions as 0.03 per cent for TAFs and 0.05 per cent for TTFs (as shown by the blue dashed line). This also shows 15 expected aircraft arrivals per year for TAFs and 27 for TTFs (also shown in Figure 20), and measured from the left side vertical axis of Figure 52.

On the right side of Figure 52, the data point labelled ‘0 to 0.25’ indicates the cumulative total of all observations below the landing minima. This can be seen by the cumulative total of forecast availability adding to 0.23 per cent, which is also shown in Figure 18 as the sum of the observations below the landing minima in the orange and light blue shading. Figure 52 also shows a maximum of 115 expected aircraft arrivals during conditions below the landing minima each year.

Operational effect of reliance on forecasting between landing and alternate minima

The middle segment of Figure 52 shows the cumulative calculation of probable aircraft affected and the cumulative percentage of all time for arrivals during observations below the landing minima by forecast worst-case minima. This shows an increase in unprimed observations and expected aircraft arrivals during these times from the alternate minima to the landing minima. This shows the effect of using a selected forecast value for operational decision making.

For example, if the alternate minima was decreased to between 1.25 and 1.5 (25 to 50 percent of the way between the landing and alternate minima), there would be an increase of around 6 unprimed aircraft arrivals per year for TAFs and 10 unprimed aircraft arrivals per year for TTFs.

Furthermore, if the landing minima was used instead of the alternate minima:

- For TAFs, 21 unprimed aircraft arrivals per year would be expected (1.42 times the number when using the alternate), making up 19 per cent of all observations below the landing minima.
- For TTFs, 39 unprimed aircraft arrivals per year would be expected (1.47 times the number when using the alternate), making up 37 per cent of all observations below the landing minima.

This shows that at typical times of day at Adelaide where a flight crew may be approaching a point of no alternate between 0 and 2 hours prior to arrival, the chances of arriving during conditions below the landing minima are increased (1.45 times for TAFs, 1.55 times for TTFs) when relying on the forecast landing minima compared with the alternate minima.

Alternate minima threshold assessment

The effect of varying the alternate minima threshold can be seen in Figure 52 looking to the number of aircraft affected and forecast availability on each side of the alternate minima line.

This shows that shifting the alternate minima 25 per cent of the way toward the landing minima would result in a slight increase in the number of aircraft affected and unprimed availability. Conversely, shifting the alternate minima 25 per cent away from the landing minima would result in a very slight decrease in unprimed observations and aircraft affected.

This suggests that overall, alternate minima criteria for visibility and ceiling are positioned at relatively stable values, with only slight benefit or loss from small perturbations. In other words, even if the alternate minima was altered slightly, there would be no significant change to the system.

Conclusions for Mildura Airport analysis

The following chapter contains a summary of conclusions formed throughout the analysis of Mildura Airport between 2009 and 2013.

- On average, one in ten days had some period where observations were below the landing minima, with half of these episodes lasting for more than 90 minutes.
- Two-thirds of episodes involved reduced visibility, one-third below ceiling, one-quarter thunderstorms.
- Peak time was between 0400 and 1000 (0700 had 12 hours per year), due to visibility and a lesser extent, ceiling, from both fog and/or mist. Thunderstorms were evenly spread across the day (1 hour per year each hour), but peaking at 1600 with 2 hours per year.
- Peak observations were in winter months (18 hours per year in July) from visibility and ceiling. Thunderstorms centred on summer months.
- Overall, it was rare for observations to be below *alternate* minima (2.6 per cent of the time), or below the *landing* minima (0.99 per cent of the time).
- Unprimed observations below the landing minima were very rare (0.09 per cent of the time). (In contrast, 13 per cent of the time were false alarms – forecast below alternate minima but observed above).
- Weather observations were unprimed mostly due to the forecasting starting late (especially from arrival time up to 2 hours prior), followed by the observations not being predicted at all (especially longer than 2 hours prior to arrival).
- The times between and around 1000 to 1100 were the most significant time of day when considering the combination of aircraft arrivals and periods of unprimed weather observed below the landing minima. This peak was mostly driven by unprimed observations below the ceiling minima.
- Mornings (0600 to 1200) had the most arrivals, and 2.4 hours of unprimed observations per year, resulting in the most aircraft affected by unprimed observations (2.2 per year). This centred on 1000. Afternoons had very little unprimed observations, while evening and early hours had very low arrivals, resulting in low estimations of aircraft affect each year (1.0, 0.4 and 0.1 respectively).
- Although many observed conditions had durations of half an hour or less (both unprimed and primed), more than half had conditions below the landing minima for more than 75 minutes.
- In the early hours and morning quadrants, retrieving a forecast earlier before arrival will increase the likelihood of arrival during unprimed observations below the landing minima.
- Each year, there were about 6 hours of unprimed observations below the visibility landing minima (which affected slightly less than 2 aircraft), while only 2.5 hours under the ceiling minima (affected slightly more than 2 aircraft per year). There was less than 1 hour a year with unprimed thunderstorms (affecting 1 aircraft per year). Crosswind had minimal effect (about 1 aircraft every 5 years).
- Using forecast conditions between the landing and alternate minima for operational decision making instead of conditions above the alternate minima considerably increases chances of arriving during unprimed observations below the landing minima.
- The alternate minima criteria for visibility and ceiling appear to be positioned at relatively stable values, with only slight benefit or loss from small perturbations.

Overview of weather affecting aviation at Mildura Airport

Between 2009 and 2013, observed conditions below published minima were not common at Mildura, with 97.0 percent of all observations being assessed as above the alternate minima. Conditions below the landing minima occurred 1.3 percent of the time, with the remaining 1.7 percent falling between the landing and alternate minima.

There were 220 discrete weather periods identified where conditions were unsuitable for landing at Mildura. This was measured from 1,598 out of 91,187 different METAR and SPECI reports, consisting of a total of 571 hours, over 210 days. One in nine days had some period of time where conditions were unsuitable for landing at Mildura. Almost half of these events had conditions recorded below the landing minima for more than 90 minutes.

There were a further 218 discrete episodes (in addition to the 220 episodes above) where conditions fell below the alternate minima criteria, however, remained above the landing minima. These occurred over a similar number of days (181) to events where conditions also fell below landing minima. These periods were considerably shorter (median 27 minutes) than periods that also deteriorated below the landing minima (median 81 minutes).

Conditions below the alternate minima and above the landing minima occurred nearly twice as often at Mildura when compared to conditions below the landing minima alone. There was more than 2 days in every 9 that had periods between the landing and alternate minima thresholds.

Generally, weather at Mildura was worst for the purposes of landing just after sunrise, peaking on average just after 0700 local time, at more than 3 times all other times of day. An elevated proportion of weather below the landing minima surrounding this peak was observed between 0300 and 1100. The weather peak was more notable between May and September each year, although it is observed throughout the year.

July had the highest prevalence of weather below the landing minima. July and June had almost twice the duration than any other month, with conditions predominantly centred around sunrise. Between November and April, there were more conditions below the landing minima in the afternoon. Weather below the landing minima in October was uncommon, with the total recorded period being almost half the duration of any other month.

Typical reasons for conditions below minima

Observed landing minima criteria

Almost three in every four events below the landing minima at Mildura were due, in part, to reduced visibility below the published threshold (Figure 53). The most common conditions below the landing minima were:

- reduced visibility below the published threshold (67 per cent of episodes)
- conditions below the published minimum ceiling for landing (43 per cent of episodes)
- thunderstorms (24 per cent of episodes)
- in excess of 10 knots tailwind or conditions below visibility and ceiling limits (20 per cent of episodes) in excess of the maximum assessed crosswind for a Boeing 737-800 (6 per cent of episodes).

The fourteen episodes involving tailwind were situations involving winds exceeding 10 knots favouring a runway with less precise instrument approaches (discussed above). In these cases, landing with all five landing minima intact is not possible, with either tailwind, visibility and/or ceiling being below the landing minima. It shows where the differences between instrument approach precision was expected to have an operational effect.

Figure 53: Weather criterion percentage of total episodes and time below landing minima for Mildura Airport[55]

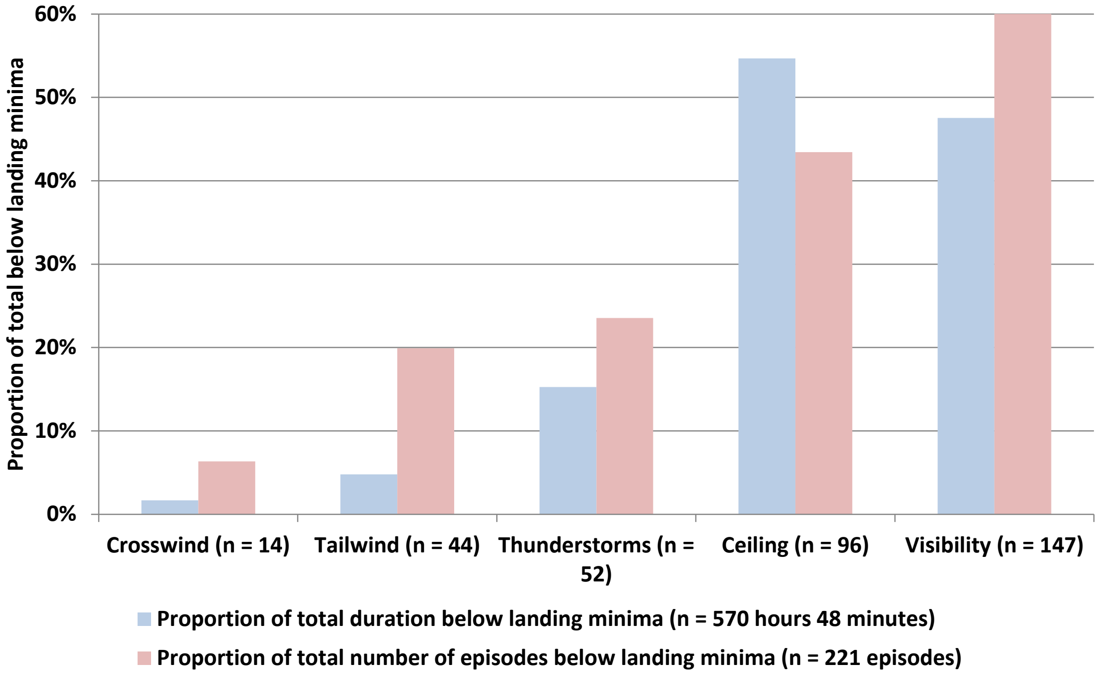


Figure 54 shows the typical duration of observed weather parameters within weather events when conditions were unsuitable for landing at Mildura Airport between 2009 and 2013.

The 'all conditions' bar in the right column shows the typical duration of weather episodes. It displays a median time of 90 minutes. The column shows typical variability around the median based on ± 1 median absolute deviation (MAD).[56] Conditions were reported for as little time as 9 minutes up to a maximum duration of 28 hours 14 minutes for *any* weather parameter below the landing minima (including combinations) (shown by the bars). The maximum value was greater than any of the individual weather parameters due to combinations of parameters existing, in this case visibility and ceiling combined. Note that multiple individual periods of weather below the landing minima are observed throughout some episodes.

The remaining columns represent the typical total time of the stated parameters, rather than representing the total time that conditions were observed below the landing minima within episodes. Weather episodes with more than one landing minima parameter breached were more likely to have longer durations of unsuitable landing conditions than shown in Figure 54, which is explored further in *Duration of observed landing minima criterion and phenomena* on page 103 below and shown in Figure 57.

When considered in isolation, reported low cloud typically endured for longer periods than any other landing minima parameter (as was also the case for Adelaide Airport), with half of all events involving landing minima ceiling breaches having periods exceeding at least 2 hours below the landing minima ceiling. The duration of low cloud in these events also had the largest variability when compared with the other parameters.

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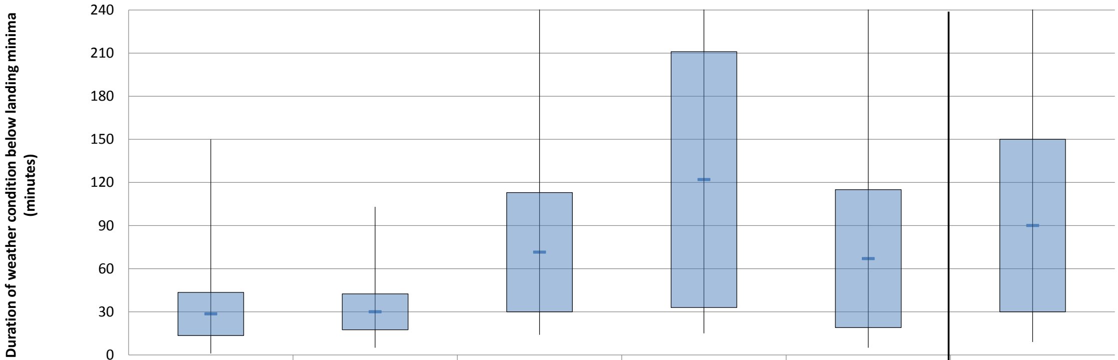
55 Proportions sum to greater than 100 per cent due to more than half of all events containing more than one type of weather parameter below the landing minima.

56 The *median absolute deviation* (MAD) is a non-parametric measure of the variability of a sample of data, roughly equivalent to 1.5 standard deviations in a normally distributed large population.

Observed visibility below the landing minima and thunderstorms had similar typical durations, with half of these events enduring for longer than 67 and 71 minutes respectively. The duration of conditions below landing minima visibility was slightly more variable than the thunderstorm duration.

Conditions where the crosswind was unsuitable for landing for a Boeing 737-800 were of a notably shorter duration than the other landing minima parameters, with half of these conditions enduring for less than 30 minutes. This also applied to periods where tailwind (in lieu of ceiling and / or visibility below minima on another runway) was greater than 10 knots.

Figure 54: Typical duration of individual observed weather parameters below the landing minima at Mildura Airport 2009 to 2013. Blue lines show medians, columns show typical variability.



	Crosswind (n = 14)	Tailwind (n = 44)	Thunderstorms (n = 52)	Ceiling (n = 96)	Visibility (n = 147)	All conditions (n = 221)
Median	28.5	30	71.5	122	67	90
Median - 1 MAD	13.5	17.5	30	33	19	30
Maximum	150	103	459	1613	597	1694
Minimum	1	5	14	15	5	9
Median +1 MAD	43.5	42.5	113	211	115	150

For most weather observation reports below the landing minima, the majority (76 percent) were the result of a single criterion breaching the published minima (as shown in Figure 105 in *Appendix A – Selected TTF, TAF and METAR/SPECI results*). However, when grouping METARs and SPECIs into a generally continuous episode of adverse weather, it was more common (75 per cent of the time and 46 per cent of episodes below the landing minima) for multiple combinations of parameters to be observed over the duration of an episode.

The higher proportion of combined conditions in the adverse weather episodes compared with individual METARs and SPECIs illustrates that although it is less common for different parameters to simultaneously breach the landing minima, it is relatively frequent for different parameters to drop below the landing minima throughout the course of an episode, and those periods are more likely to be of a notably longer duration.

Figure 55 shows the proportion of episodes by parameters causing conditions below the landing minima. Figure 56 shows the proportion of total minutes of weather below the landing minima by the parameters combined in episodes. These parameters are combined for the entirety of an episode. For example, Figure 55 shows visibility and ceiling making up 25.1 per cent of all episodes which includes situations where these are reported separately across different METARs or SPECIs grouped into the same episode, and also those with these parameters in the same observation.

Episodes with low visibility alone was the most common single parameter for conditions below the landing minima at Mildura Airport, accounting for 51 out of 221 episodes below landing minima. Episodes when both landing visibility and low cloud (ceiling) resulted in a landing minima breach were disproportionately longer in overall duration than episodes with landing visibility breaches alone. This is shown by visibility and ceiling making up 25.1 per cent of all episodes, yet making up 43.6 per cent of the total time below the landing minima, making up the largest proportion of time below the landing minima.

Sole condition breaches of thunderstorms and a low ceiling made up 14 and 8 per cent of episodes below the landing minima respectively. Only 4 per cent of episodes below the landing minima were caused by high crosswinds alone.

All episodes where only one landing minima parameter was breached throughout had a relatively lower proportion of the overall time below the landing minima, indicating that these episodes are relatively shorter on average. This is shown in Figure 57 for visibility (median 41 minutes), thunderstorms (median 60 minutes) and ceiling (median 62 minutes). Episodes below landing minima due to a high crosswind alone and tailwind during marginal visibility or ceiling (not depicted) had a median duration of about 27 minutes and 30 minutes respectively.

In contrast, all episodes where the ceiling was observed below the landing minima with visibility or visibility and thunderstorms also observed below minima had a disproportionately higher duration (medians 3 hours 43 minutes and 4 hours 11 minutes respectively) of the total time below the landing minima.

Figure 55: Number of unsuitable landing condition episodes at Mildura Airport from 2009 to 2013 by minima combination breached

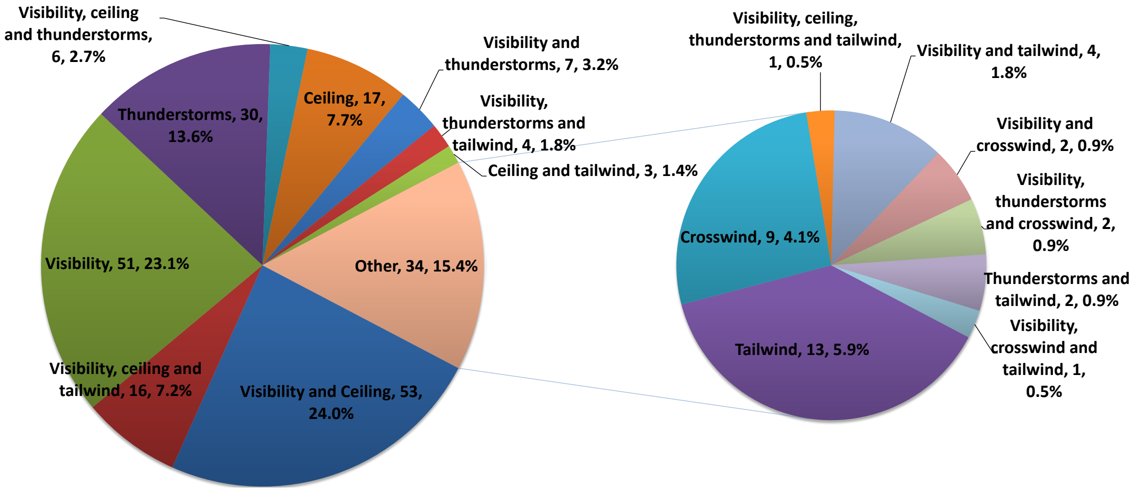
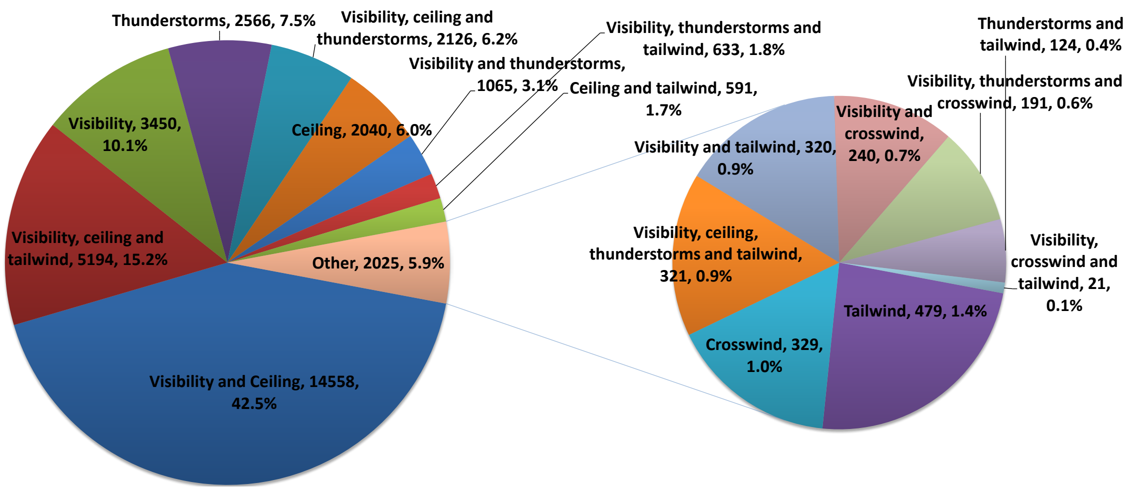


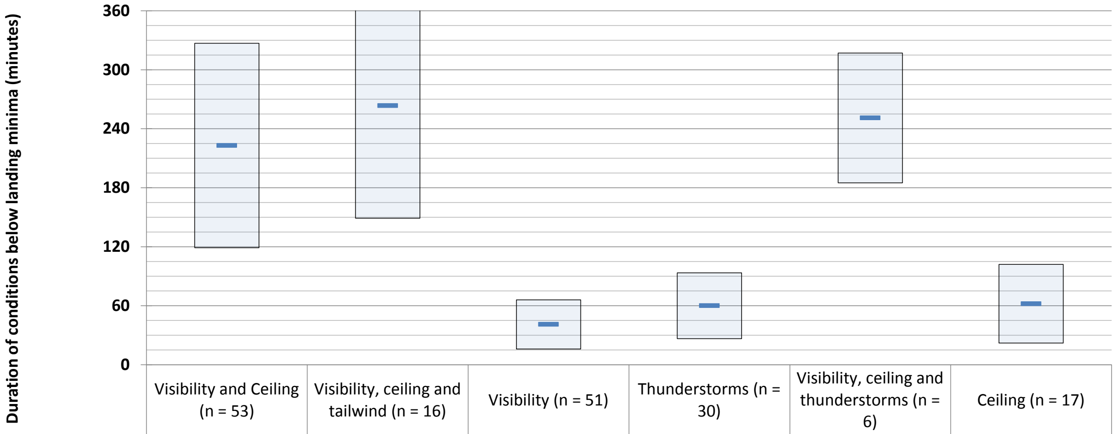
Figure 56: Duration (minutes) of episodes unsuitable for landing from 2009 to 2013 at Mildura Airport by minima combination breached



Duration of observed landing minima criterion and phenomena

The typical durations and variation of events for all parameter combinations are shown in Figure 57.

Figure 57: Typical duration of top six combined parameters breaching the landing minima within episodes at Mildura Airport 2009 to 2013 (ordered by duration below the landing minima)



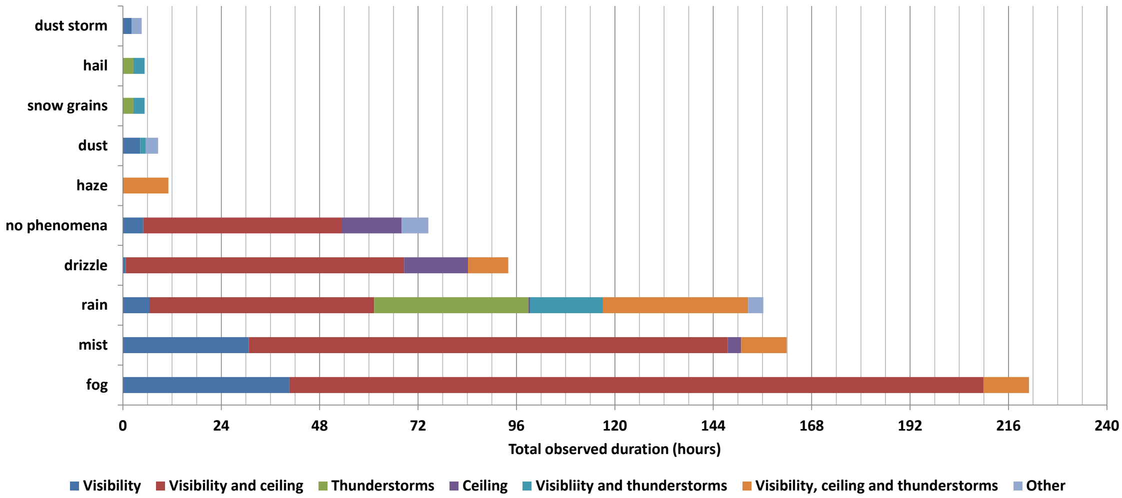
	Visibility and Ceiling (n = 53)	Visibility, ceiling and tailwind (n = 16)	Visibility (n = 51)	Thunderstorms (n = 30)	Visibility, ceiling and thunderstorms (n = 6)	Ceiling (n = 17)
Median	223	263.5	41	60	251	62
Median - 1 MAD	119	149	16	26.5	185	22
Maximum	1694	1185	310	275	667	740
Minimum	30	35	10	14	162	15
Median +1 MAD	327	378	66	93.5	317	102

Figure 58 shows the duration of weather phenomena when conditions were below the landing minima, categorised by the landing minima breached. This information is sourced from the same METAR and SPECI meteorological reports that each landing minima assessment is conducted.

Fog was the most common weather phenomena observed when conditions were below the landing minima at Mildura, with an average of more than 44 hours per year observed in 52 individual events, followed by rain and mist (Figure 58).

Conditions below the landing minima where no phenomena were recorded were the fifth most common by duration. These reports were mainly coincident with reported visibility below the landing minima.

Figure 58: Total duration of weather phenomena when conditions are below landing minima by attributing landing minima parameters 2009 to 2013



Hour of the day affect for landing minima criterion and phenomena

Figure 59 shows the hours per year that the observed weather at Mildura was below the landing minima. The blue dashed line shows that across all conditions, observations were below the landing minima peak at 0700 (over 13 hours per year), with the early morning period between 0400 and 1000 having more than 6 hours of observations (for each hour in that period) each year below the landing minima. Between 1100 throughout the afternoon and evening until 0200, there was about 2 to 3 hours of observations below the landing minima per year for each hour.

Figure 59 also shows that the peak between 0300 and 1100 is driven mostly by observed visibility below the landing minima, but also contributed to by observed ceiling below the landing minima. The visibility and ceiling landing minima criteria were very uncommon after 1100. Thunderstorms had a more even spread throughout the day (at about 1 hour per year), peaking at 1600 with 2 hours per year. (Note that more than one criteria may be present at the same time.)

Figure 59: Time of day for individual observed criterion below the landing minima at Mildura Airport 2009 to 2013. Dashed blue line shows total time any observation was below the landing minima.

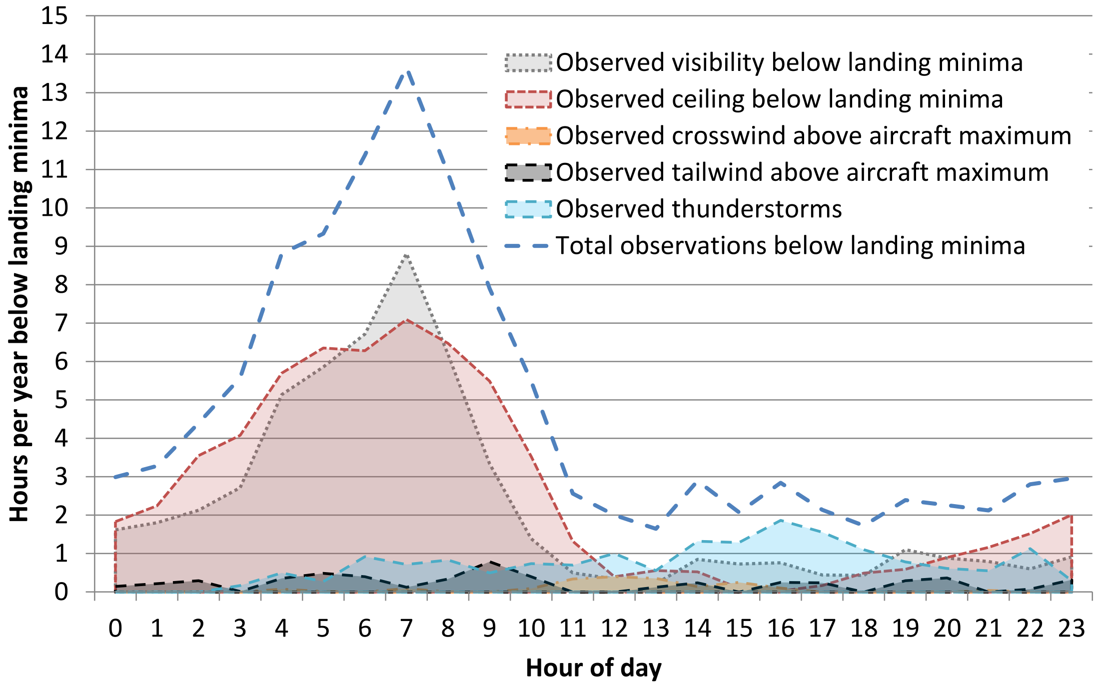
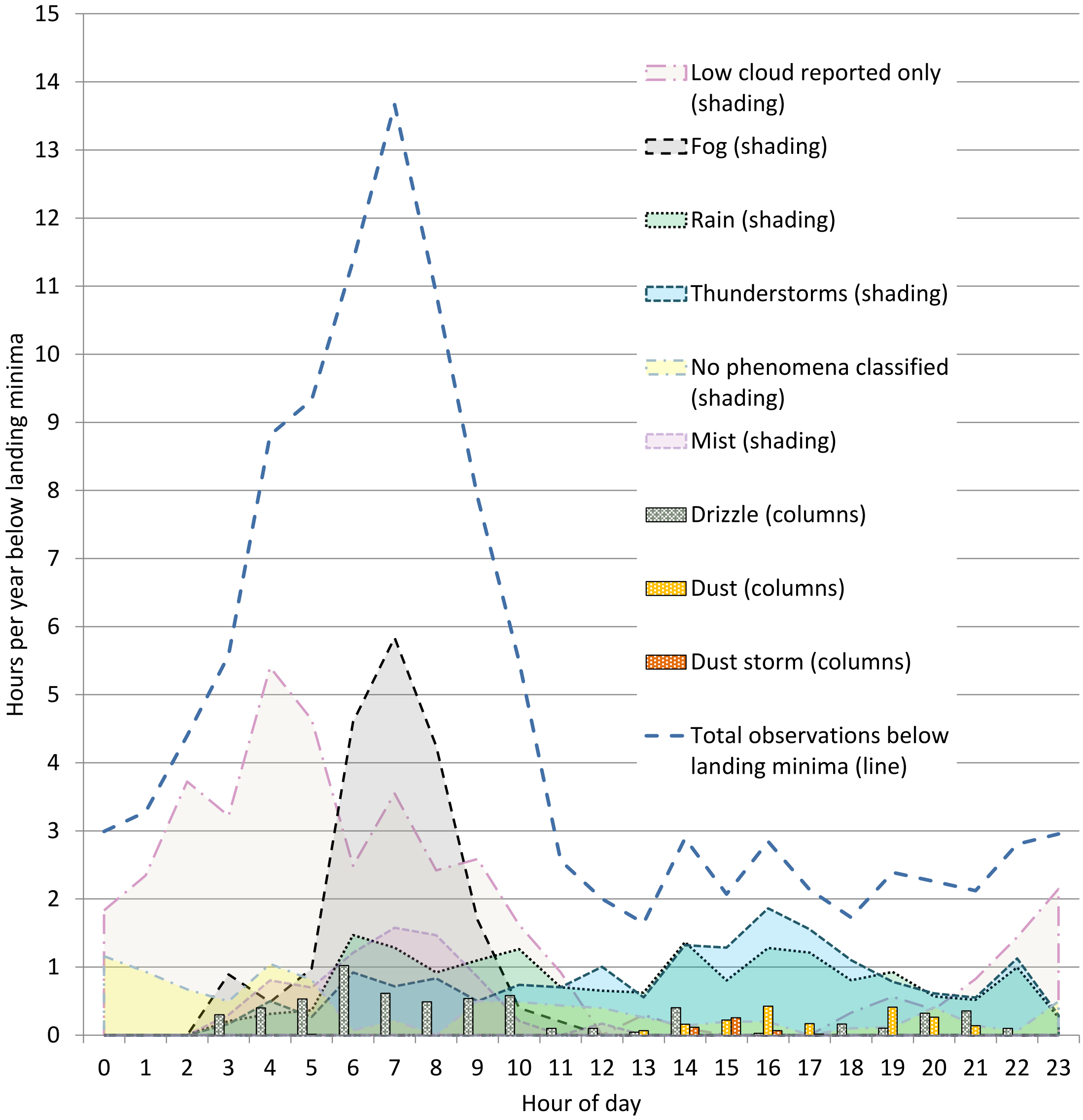


Figure 60 displays which weather phenomena were observed for each hour of the day when the observed conditions were below the landing minima.

The 0400 to 1000 peak can be seen in Figure 60 to have been driven mostly by fog. Mist, rain, thunderstorms and low cloud (when no phenomena were reported) made a smaller contribution to this period, and about half of the time mist was present, fog was also present. The period between 2300 and 0500 had a predominance of reports with no phenomena classified when observations were below the landing minima. The afternoon observations below the minima were mostly contributed to by thunderstorms and rain, 60 per cent co-occurring at the same time.

Figure 60: Time of day of individual observed weather phenomena when conditions were below the landing minima at Mildura Airport 2009 to 2013. Dashed blue line shows total time any observation was below the landing minima.

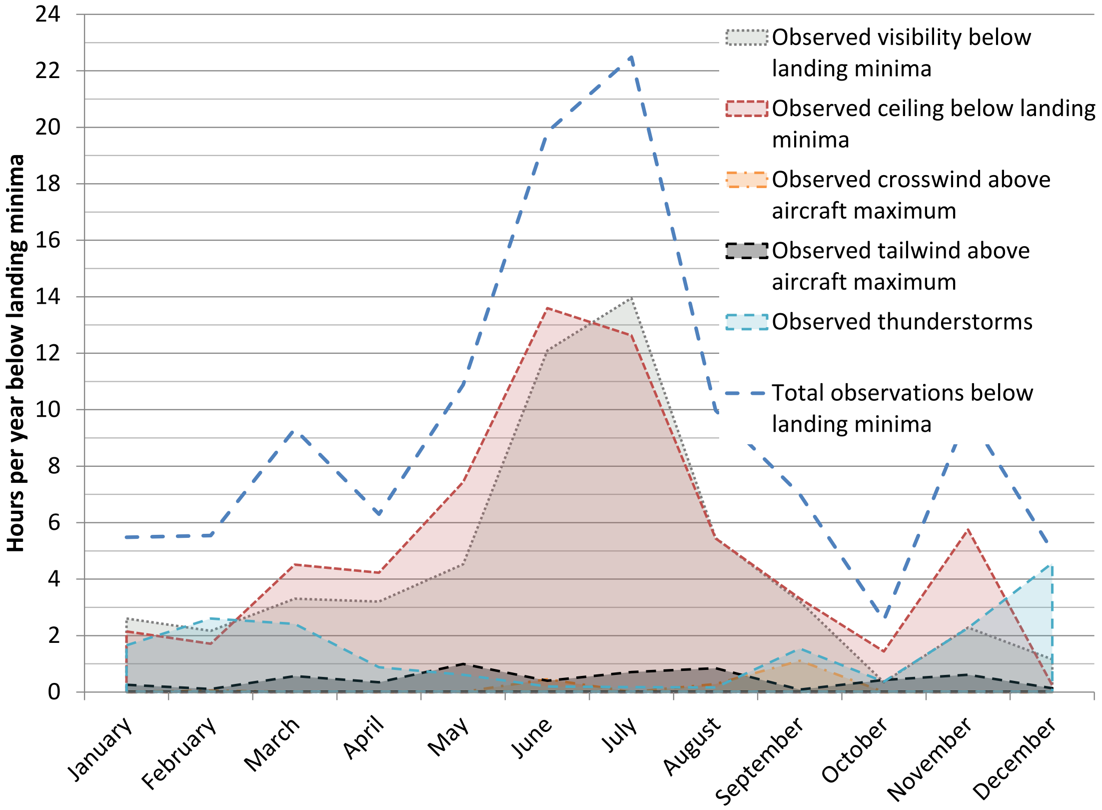


Month of year for landing minima criterion and phenomena

Figure 61 shows that July has the highest number of hours below the landing minima each year (more than 22 hours) at Mildura. Surrounding July, the colder months of May to August account for more observations below the landing minima compared with the rest of the year.

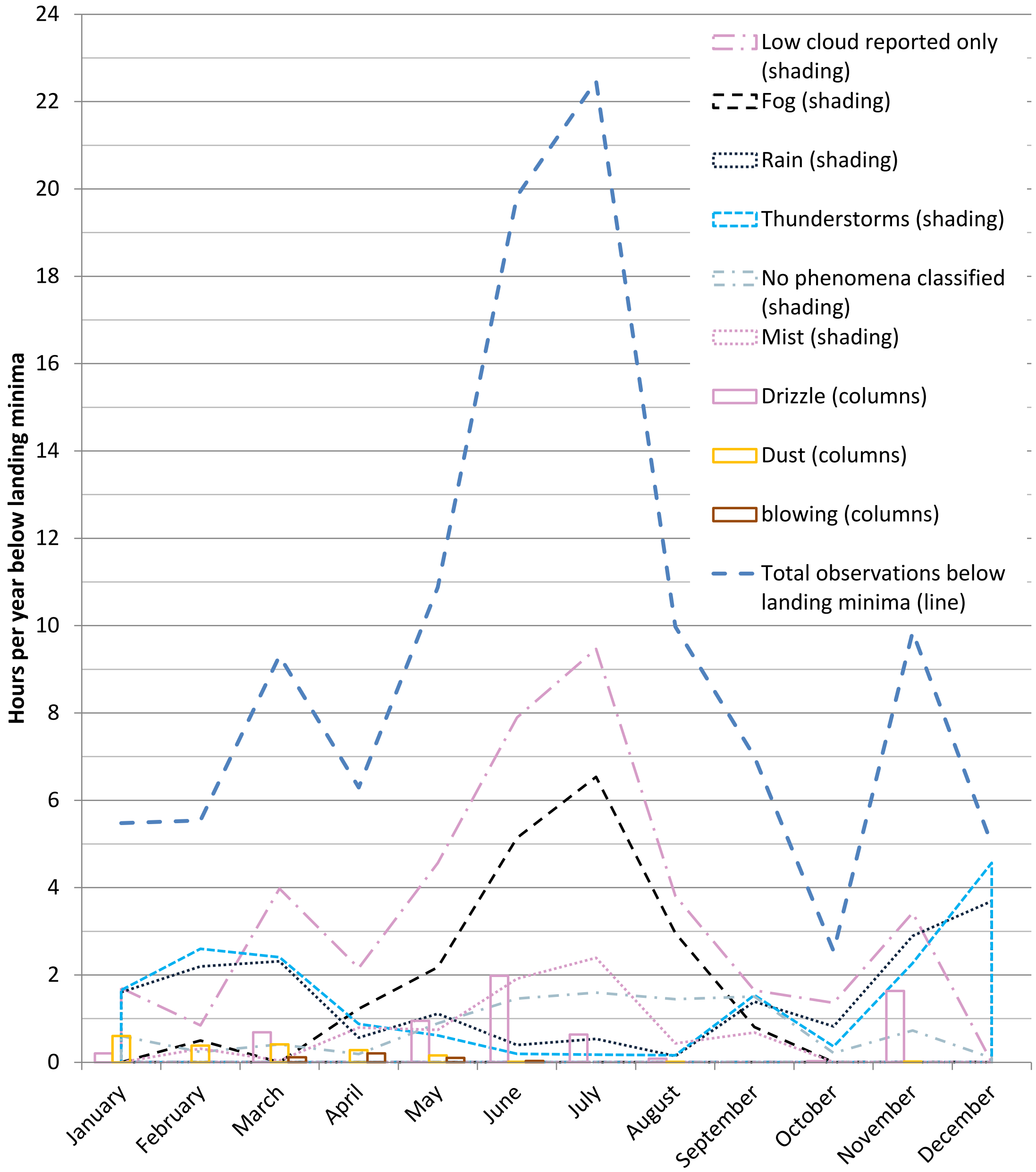
Observed visibility and ceiling were the main criterion contributing to the colder months (peaking at 14 hours per year for visibility in July and 13 hours 30 minutes for ceiling in June).. Note that more than one criteria may be present at the same time, in particular, visibility and ceiling. Observations were below the landing minima due to thunderstorms mostly in the warmer months of November through to March, peaking in December (4.5 hours per year).

Figure 61: Month of year for individual observed criterion below the landing minima at Mildura Airport 2009 to 2013. Dashed blue line shows total time any observation was below the landing minima.



Where the weather phenomena was reported, fog was the largest contributor to observations below the landing minima in the colder months of May to August (as shown in Figure 62). Mist was the second largest contributor in the colder months, although mist coincided with fog in about half of these times. Thunderstorms and rain were observed more in the warmer months of November to March, and co-occurred about 65 per cent of the time.

Figure 62: Month of the year for individual observed weather phenomena when conditions were below the landing minima at Mildura Airport 2009 to 2013. Dashed blue line shows total time any observation was below the landing minima.



The effect of forecasts on aircraft operations - Mildura Airport

Overall summary

Figure 63 shows the combinations of forecasts and the actual observed conditions (at the time the aircraft would arrive at the destination) as shown in Figure 6 above. It includes the overall likelihood of arriving at a time of unprimed observations below the landing minima[57] for retrieval times between zero and 2 hours prior to arrival, averaged every 15 minutes.[58]

Weather observations below the alternate or landing minima were rare at Mildura Airport between 2009 and 2013, with conditions:

- observed below the *alternate* minima occurring about 3.0 per cent of the time, and
- observed below the *landing* minima occurring 1.3 per cent of the time.

Unprimed observations below the landing minima (when conditions were forecast above the alternate minima) were very rare during the study period (0.10 per cent of the time and about 8 hours per year). However, considering conditions observed below the landing minima (about 1.3 per cent of the time), 1 in every 14 minutes of active forecasts[59] were unprimed - predicting conditions above the alternate minima.

When taking into account the number of discrete episodes, these occurred once in every 33 days on average. However, there are significant fluctuations in accuracy and aircraft risk to safety over time. Additionally, aspects such as aircraft holding time and traffic movements also need to be taken into account to determine the operational effect and risk.

The likelihood of a false alarm (where conditions were forecast to be below the alternate minima, however, were observed above) was significantly more likely than any time below the alternate minima no matter what forecast. More than 13 per cent of all time during the study period required alternate contingency planning when weather of this nature did not eventuate. This indicates that the overall forecasting system at Mildura is conservative in regard to the prediction of unsuitable weather for landing.

Within a period of changing weather, it was common to have a TAF (or multiple TAFs) forecasting multiple conditions over several hours, such as correct predictions (hits) and unforecast conditions (misses). Note that false alarm times are over-represented due to some of these periods occurring shortly after or prior to conditions below the alternate minima. A complete description of each field within Figure 63 can be found under Figure 6 on page 26.

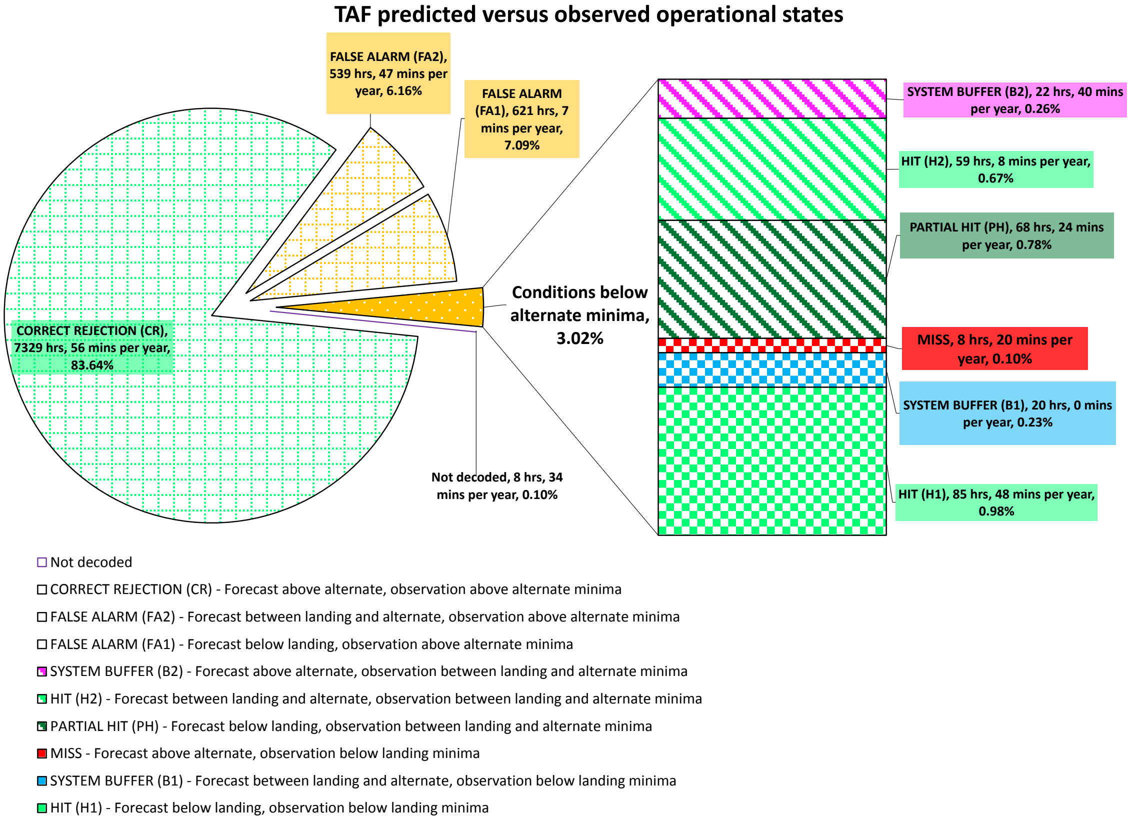
A very small number of forecasts/observations pairs (0.10%) were not decoded completely in the analysis. These appear to be evenly distributed across assessment categories and are not expected to affect the analysis.

[57] Observation of weather conditions below the landing minima preceded by a weather forecast (TAF or TTF) for conditions above the alternate minima (shown as a 'Miss' in Figure 6).

[58] Averaging between zero to 2 hours prior to arrival was chosen to indicate a typical period of time that flight crews are most likely to be affected. However, there is further analysis of individual forecast retrieval time offsets below.

[59] Active forecasts include only those forecasts publically available at a given time.

Figure 63: Percentage of total time for each forecast-observation combination for active forecast retrievals zero to 2 hours prior to arrival 2009 to 2013 – the overall likelihood of arriving at a time of unprimed observations below the landing minima was less than 0.1 per cent overall, or 7 per cent of all time below the landing minima.



Yearly trends

Weather episodes with unprimed observations below the landing minima refer to a weather episode[60] that includes a time where the forecast was above the alternate minima but had observations reported below the landing minima at the time an aircraft would have arrived at the destination. Weather episodes were formed by combining adjacent weather forecasts and observation reports together into common groups (see *Definitions and terms* on page 161).

While Figure 63 above displayed the likelihood of arriving during unprimed (red area 'Miss') and primed (green area 'Hit (H1)') observations below the landing minima, Figure 64 below shows the number of hours with unprimed (purple) and primed (transparent) observations below the landing minima for each year.

On average, there were 11 weather episodes with unprimed observations below the landing minima each year and was relatively constant between 2009 and 2013

Figure 63 above showed that when the weather conditions observed were below the landing minima, it was forecast above the alternate minima about 7 per cent of the time. The proportion of the purple to transparent columns in Figure 64 below shows this is generally the case for each year in the study period. In addition, the data labels in Figure 64 show, averaged across the years, about two in seven weather episodes with observed conditions below the landing minima had forecasts above the alternate minima. However, this does not necessarily indicate that there was an elevated safety risk to aircraft in each case, with factors such as the time of aircraft arrivals and

60 A *weather episode* is any period *outside* of when both the forecast AND observed weather were above the landing minima (correct rejection).

the unexpected period of holding also affecting the overall risk of a situation. Time of calculated holding is discussed further in the *Methodology summary* on page 28.

The rate of weather episodes with unsafe conditions was calculated to be just over 240 per 100,000 arrivals in each year.[61] This equates to about 1 in 415 aircraft arrivals. Note that the time of arrival and time of year play a significant role affecting the likelihood of retrieving a non-predicting forecast, which is reflected in the fluctuations in the expected numbers of aircraft arrivals during unprimed observations each year.

Taking into account the time of day, differences between months, and weekday (Monday to Friday) or weekend (Saturday or Sunday) day, an estimate of the number of aircraft arrivals affected was calculated.[62]

It can be seen that the expected number of aircraft arrivals (red shading in Figure 64) during unprimed observations below the landing minima does not consistently vary across the years with the hours of unprimed observations. Averaged across the years, about 3.6 aircraft arriving at Mildura were affected each year by unprimed observations below the landing minima, ranging from between 1 or 2 aircraft in 2012 to seven in 2013.

Figure 64: Hours of unprimed and primed observations below the landing minima by year, averaged over retrieval periods up to 2 hours prior to arrival. Column labels indicate the number of weather episodes for each category and are additive. Lines represent aircraft arrivals and expected aircraft arrivals during unprimed observations.

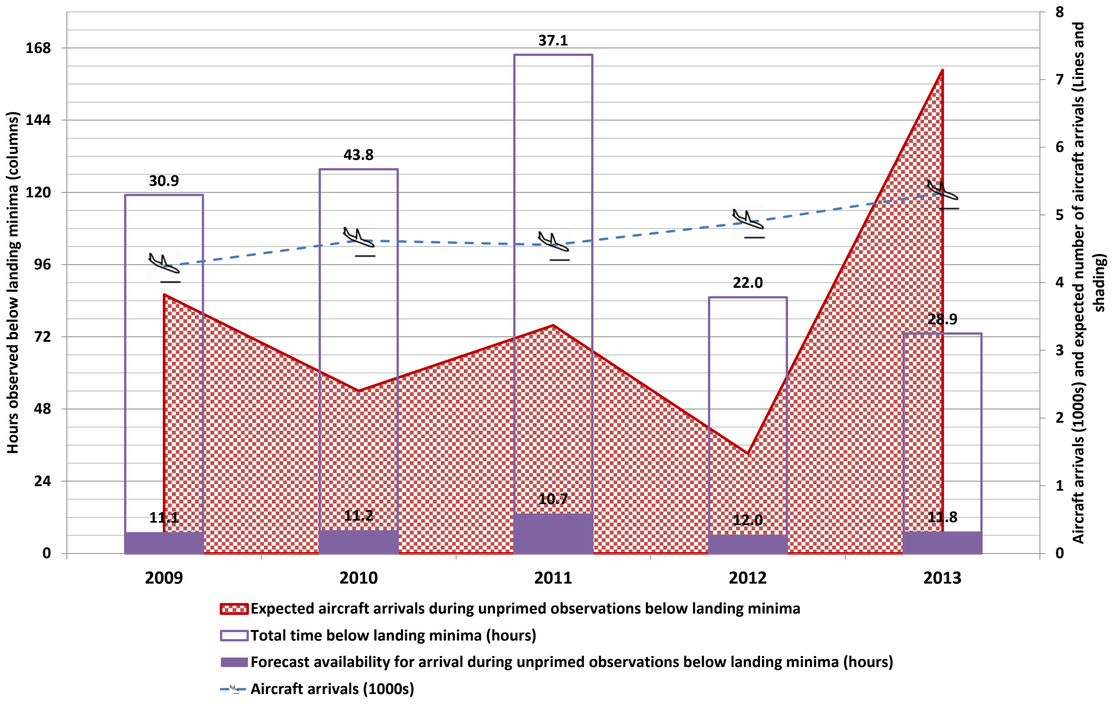


Figure 65 shows the median time a forecast was available, per weather episode, where an aircraft may have arrived during unprimed observations below the landing minima. Retrieval times for active forecasts[63] between zero and 2 hours prior to arrival were used, calculated every 15

[61] Aircraft arrivals data were only available between 2010 and 2013. Arrivals were estimated for 2009 based on a linear interpolation of 2010 to 2013 arrivals.

[62] As aircraft arrivals data were only available between 2010 and 2013, aircraft affected for 2009 was calculated in the same way as other years except these data were normalised using the interpolated arrivals for 2009.

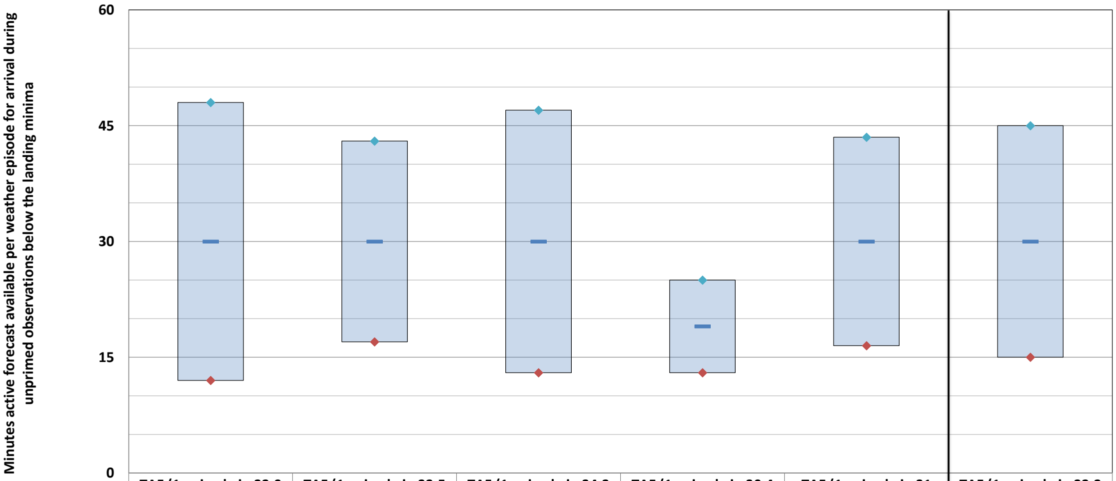
[63] Active forecast refers to a single component of a TAF used for operational decision making at a particular point in time. Note that there can only be one TAF forecast active at a given time.

minutes. The average frequency of these weather episodes with unprimed observations is displayed by year in the horizontal-axis label, for example in 2009 these occurred about 1 in every 32.9 days. Maximum and minimum values are shown in the table below. It is also important to note that there was significant monthly and hourly variation in likelihood which is explored below.

The differences across years (with the exception of 2012) were relatively small and only had a slight effect on the overall likelihood of arriving during unprimed observations below the landing minima after retrieving a forecast. When there were unprimed observations below the landing minima at Mildura, the median time that those forecasts were available was 30 minutes per weather episode, occurring once in every 32.2 days on average.

The longest single available forecast occurred in 2011, with unprimed observations available in the active forecast for 7 hours and 30 minutes. However, this period was between 2200 and 0600 in the morning where there are typically very low numbers of aircraft arrivals.

Figure 65: Typical time a forecast was available, per weather episode, where an aircraft theoretically could have arrived during unprimed observations below the landing minima, by year, calculated for retrieval periods zero to 2 hours prior to arrival



	TAF (1 episode in 32.9 days) 2009	TAF (1 episode in 32.5 days) 2010	TAF (1 episode in 34.2 days) 2011	TAF (1 episode in 30.4 days) 2012	TAF (1 episode in 31 days) 2013	TAF (1 episode in 32.2 days) Total
Median	30	30	30	19	30	30
Median - 1 MAD	12	17	13	13	16.5	15
Maximum	114	143	450	137	212	450
Minimum	1	2	4	2	1	1
Median +1 MAD	48	43	47	25	43.5	45

Based on Figure 64 and Figure 65, there is no systemic trend across the years. As a result, further analysis below will be grouped across the 5-year period.

Time of day

The frequency of all observations below the landing minima varied significantly at Mildura across the 24 hour day. This is can be seen by the combined solid and transparent columns in Figure 66 below. Variation also differs between active forecasts above the alternate minima (solid columns) and active forecasts below the alternate minima (transparent columns) across the 24 hours (also see Figure 67 below). Many of these observations below the landing minima coincided with times outside of the common arrival times for aircraft landing at Mildura (blue line).

Figure 66: Hours active forecasts were available for unprimed and primed observations below the landing minima (columns), thousands of aircraft arrivals (blue line), and expected aircraft arrivals during unprimed observations below the landing minima (red shading) per year, by hour of day, averaged for forecast retrieval times between zero to 2 hours prior to arrival 2009 to 2013. Column labels indicate the number of weather episodes per year for each category and are additive.

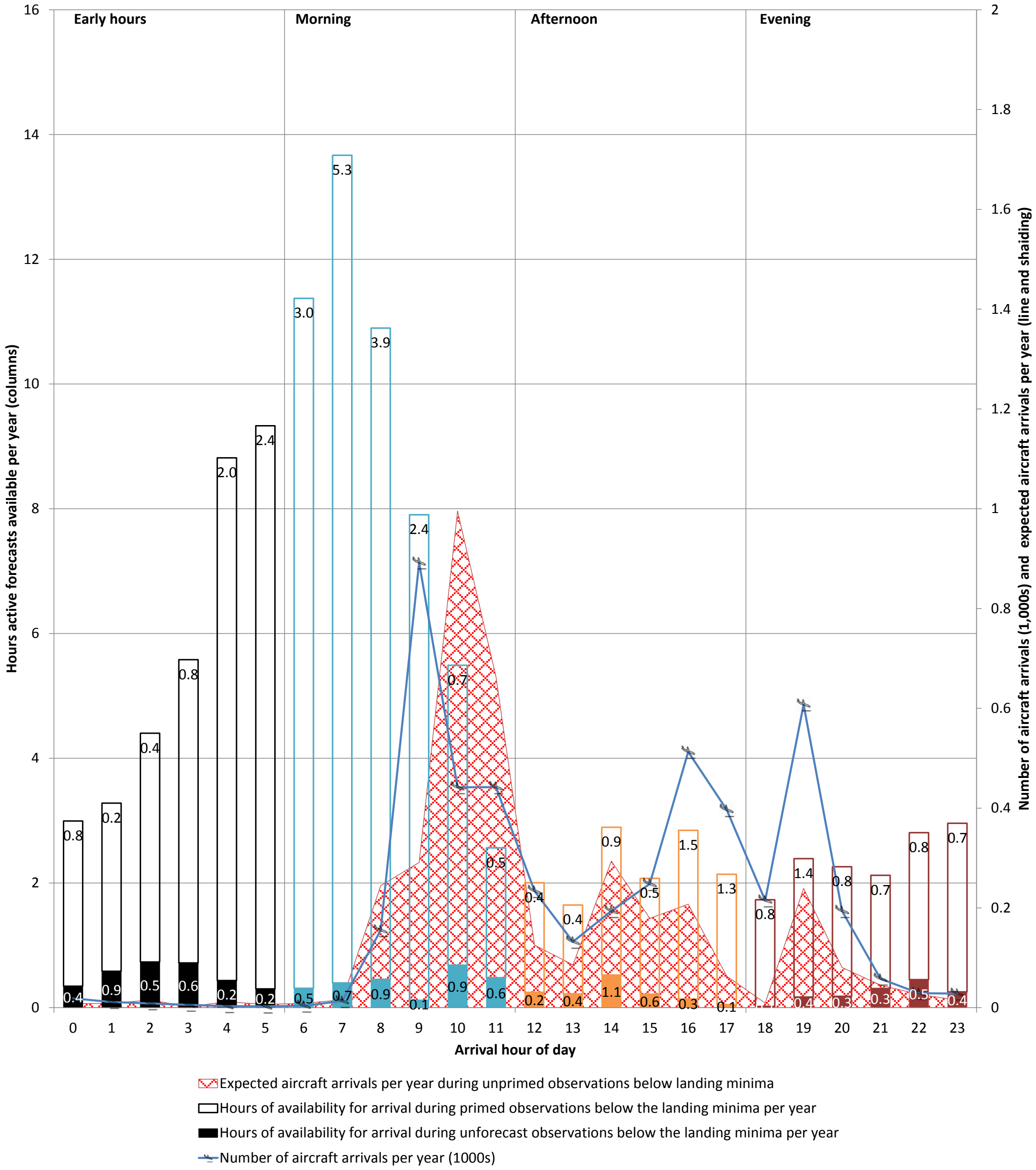


Figure 66 above also shows the estimated number of aircraft affected each year by unprimed observations below the landing minima by hour of day (red shading). The most common time that aircraft would have been affected by unprimed conditions was between 1000 and 1100 (and surrounding hours from 0800 to 1200). Between 1000 and 1100, it was estimated that 1.0 aircraft were affected per year on average.

The hour from 0900 to 1000 represents the hour of day where the most aircraft arrived, and coincided with a high number of total hours below the landing minima (either primed or unprimed). Between 1000 and 1100, however, more aircraft were affected by unprimed observations due to the higher hours of availability of unprimed observations below the landing minima even though there were a lower number of arrivals.

There were also aircraft affected by unprimed weather observations at relatively smaller peaks from 1400 to 1500, driven by both aircraft arrivals and forecasting and 1900 to 2000, driven predominantly by aircraft arrivals and to a lesser extent the availability of forecasts with unprimed conditions.

While there are relatively low numbers of affected aircraft in the early morning, when there was a higher availability of forecasts with unprimed conditions (from midnight and 0600), there was a higher likelihood per arrival for any aircraft electing to arrive during this time.

Due to differences across the day, much of the analysis below is broken into quadrants of the day, as shown in Table 7.

Table 7: Day quadrants, showing arrivals and hours of observations below the landing minima, averaged per year

Quadrant name	Quadrant time	Arrivals per year	Total hours observed below the landing minima	Unprimed hours observed below the landing minima	Expected aircraft arrivals during unprimed conditions
Early hours	0000 to 0559	51	34.4	3.1	0.1
Morning	0600 to 1159	1,949	51.9	2.4	2.2
Afternoon	1200 to 1759	1,718	13.6	1.4	1.0
Evening	1800 to 2359	1,132	14.3	1.4	0.4

Figure 67 below displays the same columns as Figure 66 above but as 100 per cent for each hour of day, so that the ratio between primed and unprimed conditions below the landing minima can be more easily seen. The line in Figure 67 displays the total time (both primed and unprimed) below the landing minima. This graph indicates the proportion of observations below the landing minima that were unprimed.

The peak time of the day for all observations below the landing minima was in the morning, just after dawn between 0600 and 0900 (dotted line in Figure 67). Despite being the most prevalent period for weather below the landing minima, the hours between 0600 and 0900, along with 1600 to 1900, had the lowest proportion of unprimed weather. This indicates a higher relative reliability of forecasting during the morning when observations below the landing minima are also the most prevalent.

The proportion of unforecast events surrounding the primary weather peak (centred during 0700 and 0800) appears to be inversely proportional to the magnitude of observed weather below the landing minima. This may indicate that while the typical weather phenomena and conditions associated with this peak are able to be readily predicted, determining when the weather will start and how long it will remain proves to be more problematic. This is explored in *Characteristics of unprimed observations on page* 132.

Peak times for unprimed observations below the landing minima occurred between 0100 and 0300. Other times of higher proportions of unprimed conditions were from 2100 to midnight, and 1000 to 1200.

Figure 67: Unprimed observations as a percentage of all time below the landing minima for each hour of day, averaged for simulated TAF retrieval times between zero to 2 hours prior to arrival 2009 to 2013

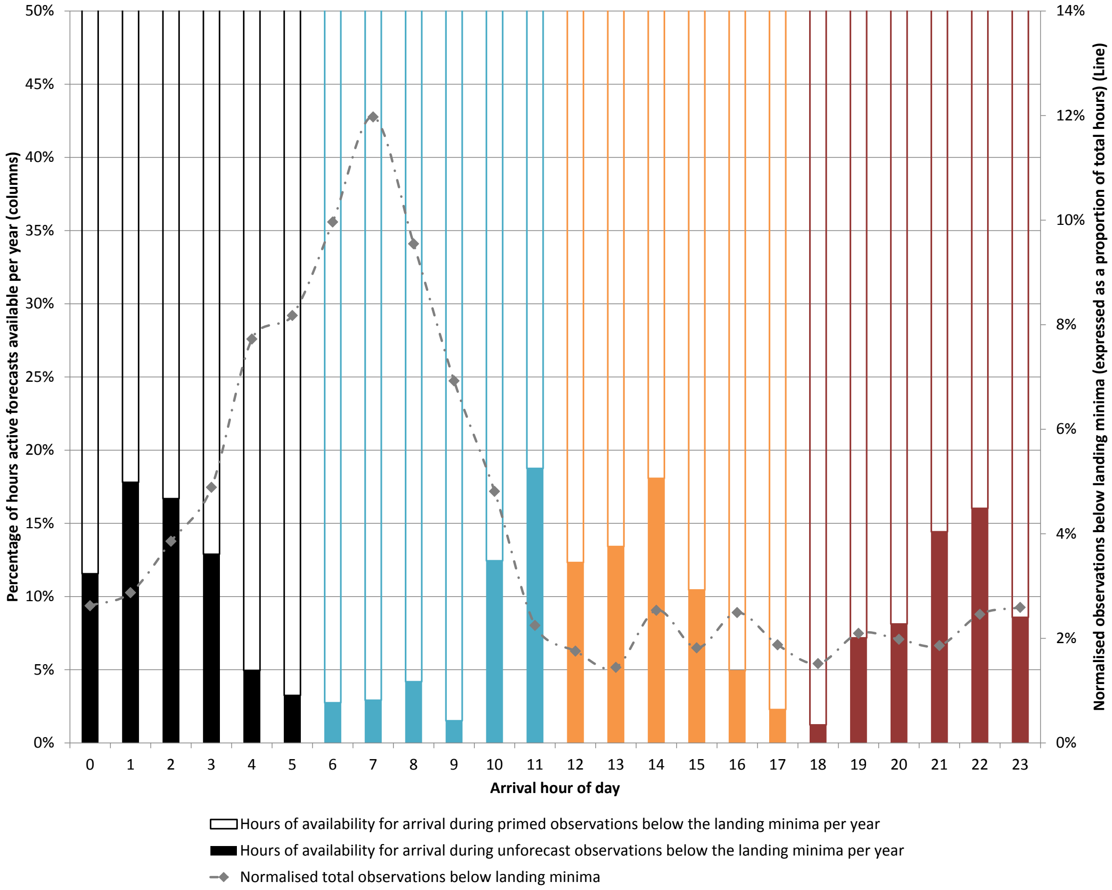


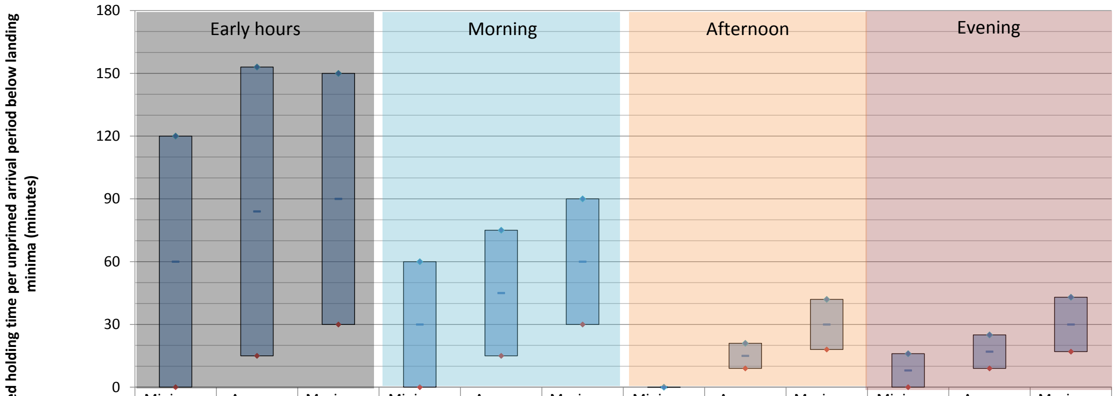
Figure 68 shows the estimated average (middle bars), minimum (left bars) and maximum (right bars) calculated holding time for each quadrant of the day. Estimated holding time is the time that an aircraft would have to expectantly hold following arrival in conditions below the landing minima after the retrieval of a forecast above the alternate minima. It takes into account the forecast that a flight crew would have received and the time observations remain below the landing minima after arrival and/or a change in the forecasted conditions in the same TAF after arrival. See *Unexpected holding time range* on page 35 for more details.

Figure 68 shows that the early hours have longer estimated holding times, and a greater variation in holding times, than the other times of the day. Half of all unprimed arrival periods in the early hours had an average holding time greater than 84 minutes, the highest of all quadrants of the day. In contrast, the morning had a relatively lower variation and lower medians, although half of all unprimed arrivals periods were greater than 45 minutes. The afternoon and evening had even lower estimated holding times, with smaller variation, with half of all these arrivals periods having an estimated holding time of less than 15 and 17 minutes respectively.

This highlights that during the day, particularly in the morning, there are still times when estimated holding will be longer than standard fuel reserves of arriving aircraft (usually between 20 and 45 minutes[64]).

[64] An additional variable reserve of up to 15 per cent applies to some aircraft – see CAAP 234-1 for details.

Figure 68: Estimated holding time for forecasts with unprimed observations below landing minima for each quadrant of day, averaged for forecast retrieval times between zero to 2 hours prior to arrival 2009 to 2013[65]



	Minimum Early hours (0000 to 0600) (n = 14)	Average Early hours (0000 to 0600) (n = 14)	Maximum Early hours (0000 to 0600) (n = 14)	Minimum Morning (0600 to 1200) (n = 18)	Average Morning (0600 to 1200) (n = 18)	Maximum Morning (0600 to 1200) (n = 18)	Minimum Afternoon (1200 to 1800) (n = 14)	Average Afternoon (1200 to 1800) (n = 14)	Maximum Afternoon (1200 to 1800) (n = 14)	Minimum Evening (1800 to 0000) (n = 10)	Average Evening (1800 to 0000) (n = 10)	Maximum Evening (1800 to 0000) (n = 10)
Median	60	84	90	30	45	60	0	15	30	8	17	30
Median - 1 MAD	0	15	30	0	15	30	0	9	18	0	9	17
Maximum	449	455	460	298	299	300	144	147	150	119	121	123
Minimum	0	6	12	0	5	10	0	3	6	0	5	9
Median + 1 MAD	120	153	150	60	75	90	0	21	42	16	25	43

Monthly trend

Weather observations and forecast reliability also vary across the months of the year. Figure 69 shows both unprimed (solid columns) and primed (transparent columns) observations below the landing minima across the 12 months of the year, separately for each quadrant of the day

Figure 69 below shows significant monthly fluctuation in both unprimed and primed observations across the months, with a similar pattern seen in the early hours and morning quadrants, and in the afternoon and evening quadrants.

The mornings and early hours have the highest monthly hours of observations below the landing minima in general, but specifically in the cooler months of May through to September, peaking at about 14 hours per year for the morning quadrant in July. The cooler months also correspond to the months with the most hours of unprimed weather in the mornings and early hours, along with January in the early hours. There were was about one hour per year of unprimed observations below the minima in July mornings and January early hours. Additionally, June and July early hours had more than 42 minutes of unprimed observations per year.

In the afternoon and evening quadrants, there were less hours of observations below the landing minima across the months. For the afternoons, February to April (peaking in March with about 2.1 hours per year of observations below the landing minima) and for the evening, November to January (with about 2.7 hours per year in November and 2 hours per year in January) had the most weather observed below the landing minima. Interestingly, there was another peak month in June with 2.2 hours per year of observations below the landing minima. The afternoon had a maximum of about 20 minutes of unprimed observations per year for any one month (September), followed by May. In the evening, unprimed observations peaked in January with 36 minutes per year, with other months considerably lower, with February, November and December having a maximum of 14 minutes each per year in the evening.

Aircraft affected mostly occurred in the morning quadrant following the higher number of arrivals and the more hours of unprimed observations. The most common time for aircraft to be affected

65 Median holding times were calculated from estimated holding times for each unprimed hour within each daily quadrant.

was in the mornings in July, with 1.2 each year. About 2 aircraft every 5 years are expected to arrive during unprimed observations in the morning for June, and 1 in every 4 years in April.

In the afternoons and evenings, generally no aircraft were expected to arrive during unprimed observations in most months due to a lower number of unprimed observations, with some months having no unprimed observations. Peaks of about one aircraft being affected every five years or less were found in some months reflecting a small amount of unprimed observations (Figure 69). In the early hours, virtually no aircraft were affected in all months due to the very low number of arrivals.

Figure 69: Hours active forecasts were available for unprimed and primed observations below the landing minima (columns), thousands of aircraft arrivals (blue line), and expected aircraft arrivals during unprimed observations below the landing minima (red shading) per year, by month for each quadrant of day, averaged for simulated forecast retrieval times between zero to 2 hours prior to arrival 2009 to 2013. Column labels indicate the number of weather episodes per year for each category and are additive.

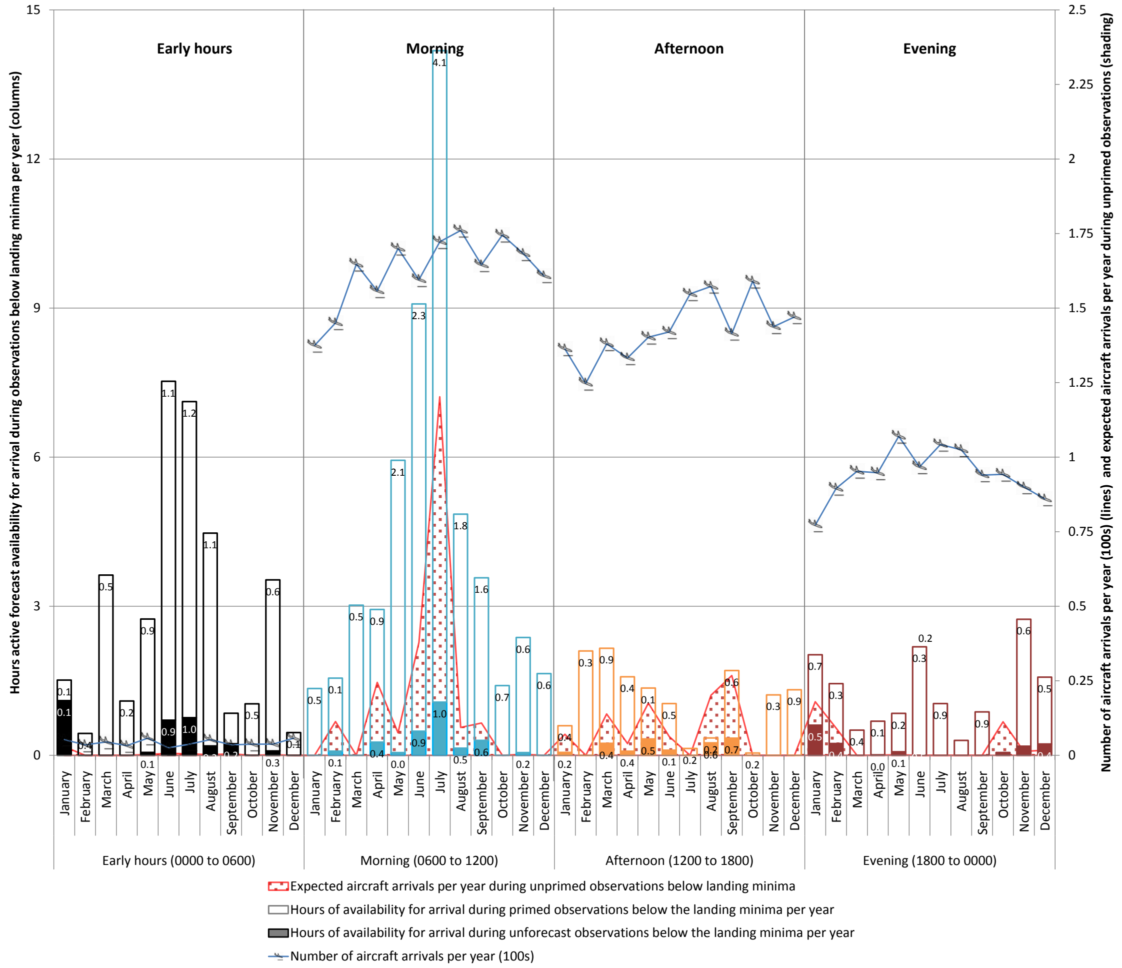


Figure 70 below displays the same columns as Figure 69 above, in the same format as Figure 67 above, however showing the relative reliability of forecasting by quadrant of day and month. The line in Figure 70 indicates the total relative time (both primed and unprimed) below the landing minima, also as shown in Figure 67.

The total number of observations below the landing minima (dashed line) in Figure 70 shows when the accuracy of forecasts has a larger effect (also shown by the height of the solid bars in Figure 69 above).

The largest proportions of observations below the landing minima that were unprimed were evenings in October (100%), afternoons in August (71%) and early hours in January (73%). In October evenings and early hours in January observations below the landing minima were rare (about one episode in every 5 and 3 years respectively) which may have contributed to the unprimed observations. August afternoons, episodes below the landing minima were expected four in five years, however these were relatively short in duration (shown by the grey dashed line).

Other notable periods for forecast reliability were early hours in September (unprimed 27% of the time), afternoons in May (24%) and September (20%), and evenings in January (30%) and February (16%).

The main peak of observations below landing minima in July mornings was similar to the overall average, with about 1 in every 13 minutes of observations being unprimed.

Figure 70: Unprimed observations as a percentage of all time below the landing minima for each month and quadrant of day, averaged for simulated TAF retrieval times between zero to 2 hours prior to arrival 2009 to 2013

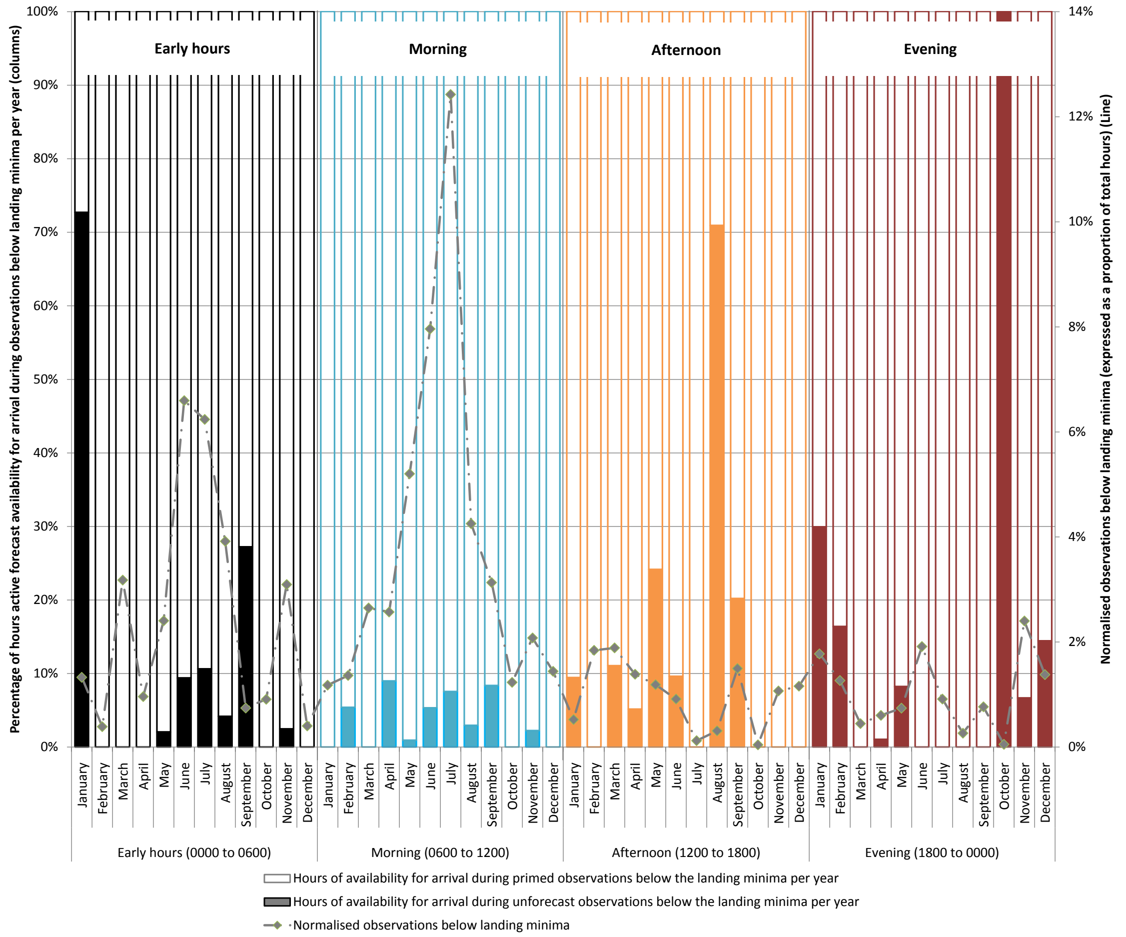


Figure 71 below shows the median estimated holding times that an aircraft was expected to encounter after arriving during an unprimed observation below landing minima. As described in *Unexpected holding time range* on page 35 for more details, each holding period has three calculated values – minimum, average and maximum. This is indicated by the blue bars, which display the monthly medians from a combined dataset of 15 minute increments of forecast retrieval time prior to arrival from zero to 2 hours.

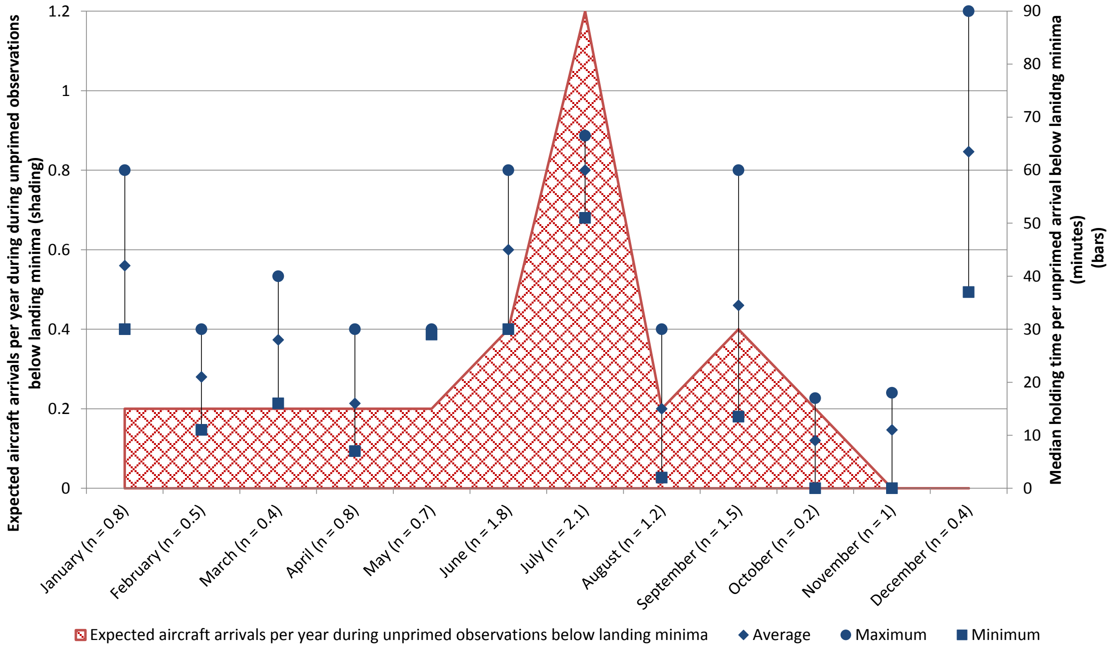
The red shading on Figure 71 indicates the expected number of unprimed aircraft arrivals per year in each month. The monthly horizontal axis labels also show the average number of episodes in each month per year, for example July had an average of 2.1 unprimed episodes per year.

December had the highest median values for the minimum, average and maximum estimated holding time. December also had the largest variation between median values ranging from 37 to 90 minutes. However, the number of aircraft typically affected in December was very low, due to the combination of relatively low numbers of unprimed observations below landing minima and these observations falling outside typical aircraft arrival times.

A number of months had at least half (the median) of the average estimated holding times greater than 30 minutes in duration where aircraft were more likely to be affected. Specifically, July (60 minutes), June (45 minutes), January (42 minutes) and September (34 minutes).

The combination of probable aircraft affected (likelihood) and holding time (severity) can be used to provide an indication of the relative risk by month that unprimed observations have on aviation safety. July had the largest number of probable aircraft affected, stemming from the largest number of unprimed observations below landing minima during the high morning air traffic period as shown in Figure 69 above.

Figure 71: Estimated holding time for episodes with unprimed observations below landing minima and expected unprimed aircraft arrivals for each month, averaged for simulated TAF retrieval times between zero and 2 hours prior to arrival 2009 to 2013. Horizontal axis labels indicate the number of weather episodes per year for each month.



Time of the day by month

In the same way that Figure 66 and Figure 69 show the peak times of unprimed observations below the landing minima by hour of day and months by quadrants respectively, Figure 72 shows the peak periods by month and hour of day. The coloured contours show the total time in hours per year, as labelled in the legend below. Note the graph is wrapped around at the end of the year to show continuity and data points are situated on depicted gridlines.

The most common time for unprimed observations below landing minima was between 1000 and 1100 in July, with about 24 minutes per year of forecast availability. This also corresponds to the peaks in Figure 66 and Figure 69. Another peak exists between 0100 and 0300 in June and 0300 and 0400 in July, with about 17 minutes of forecast availability per year.

Several other periods of generally elevated unprimed observations also existed:

- between June and September between midnight and 1300 in the afternoon
- throughout January between midnight and 0600
- between November and January from 1800 to midnight.

There were no unprimed observations from March to September between the hours of 1800 and 2300. Additionally, no unprimed observations were identified between 0800 and 1500 from October through to January in any year.

This graph highlights the seasonal and daily fluctuations of unprimed observations below the landing minima and shows areas that could be focused on for improved forecasting, in particular, 1000 to 1100 during July.

Figure 72: Hours active forecasts were available leading to unprimed observations below the landing minima per year, by hour of day and month, averaged for simulated TAF retrieval between 0 and 2 hours prior to arrival 2009 to 2013

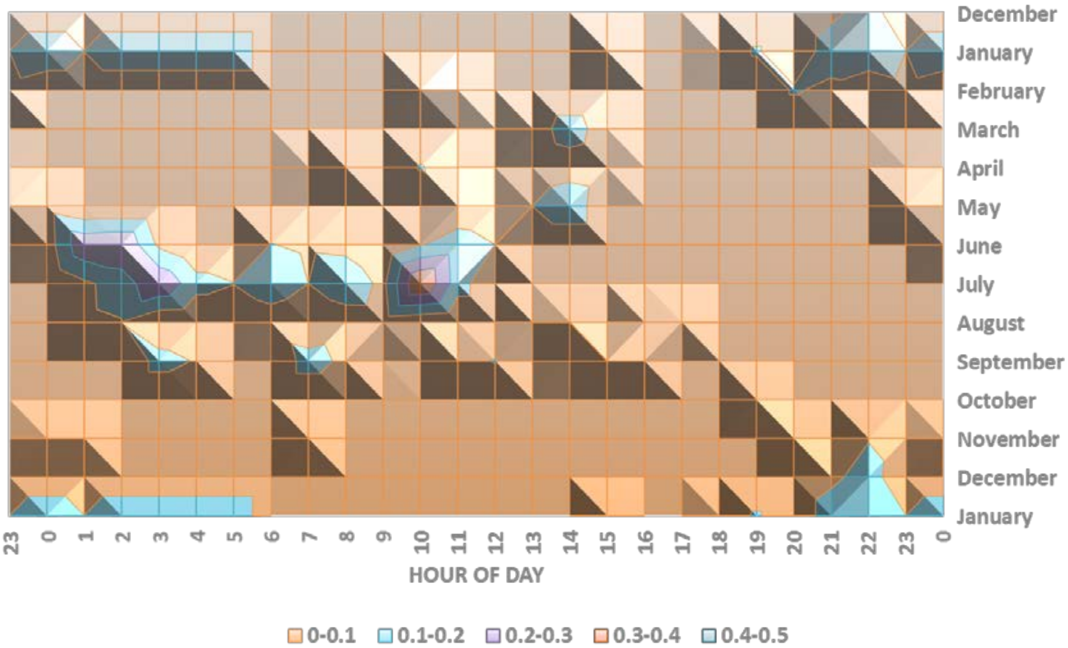


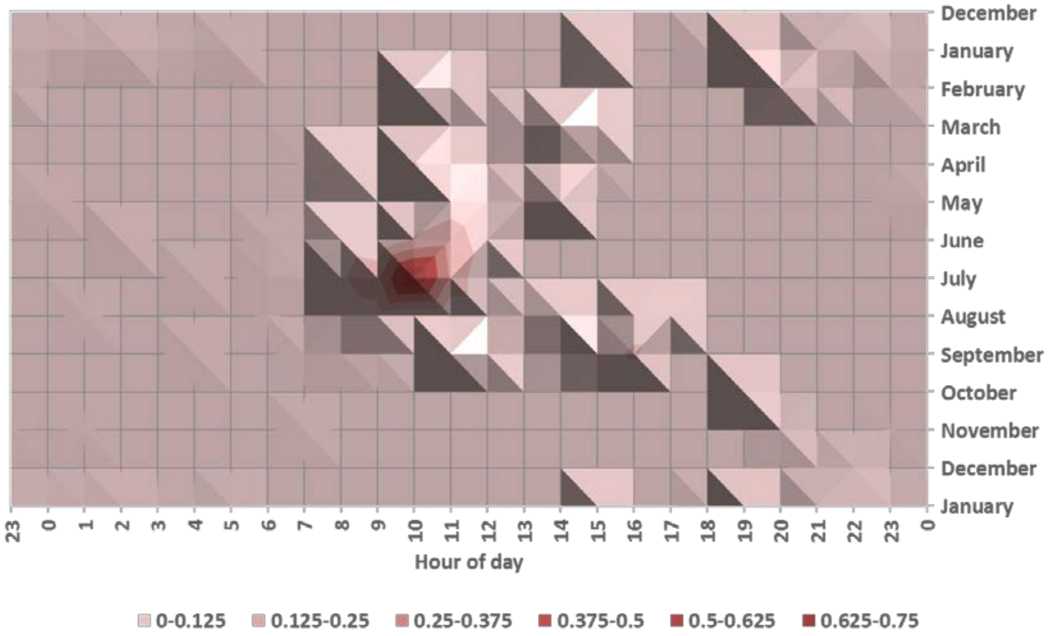
Figure 73 shows the expected number of aircraft arrivals during unprimed weather observations for each month and each hour of the day. It was seen in Figure 69 above that the largest numbers of aircraft affected were in the mornings in July, followed by afternoons in September.

It can be seen in Figure 73 that unprimed aircraft arrivals were expected in July from 0800 to 1200, and between 0900 and 1100 in particular. This makes up about one third of all expected unprimed aircraft arrivals, equivalent to about six aircraft exposed to unprimed observations below the landing minima every five years.

For September, the unprimed observations were focused at 1600, where one aircraft is expected to be affected every seven years.

The smaller peak in January was from 1900 to 0400, mostly driven by the availability of unprimed forecasts, but was also influenced by traffic between 1900 and 2000.

Figure 73: Expected aircraft arrivals per year, by hour of day and month during observations below the landing minima following averaged simulated retrieval of unprimed TAF retrieval between 0 and 120 minutes prior to arrival 2009 to 2013

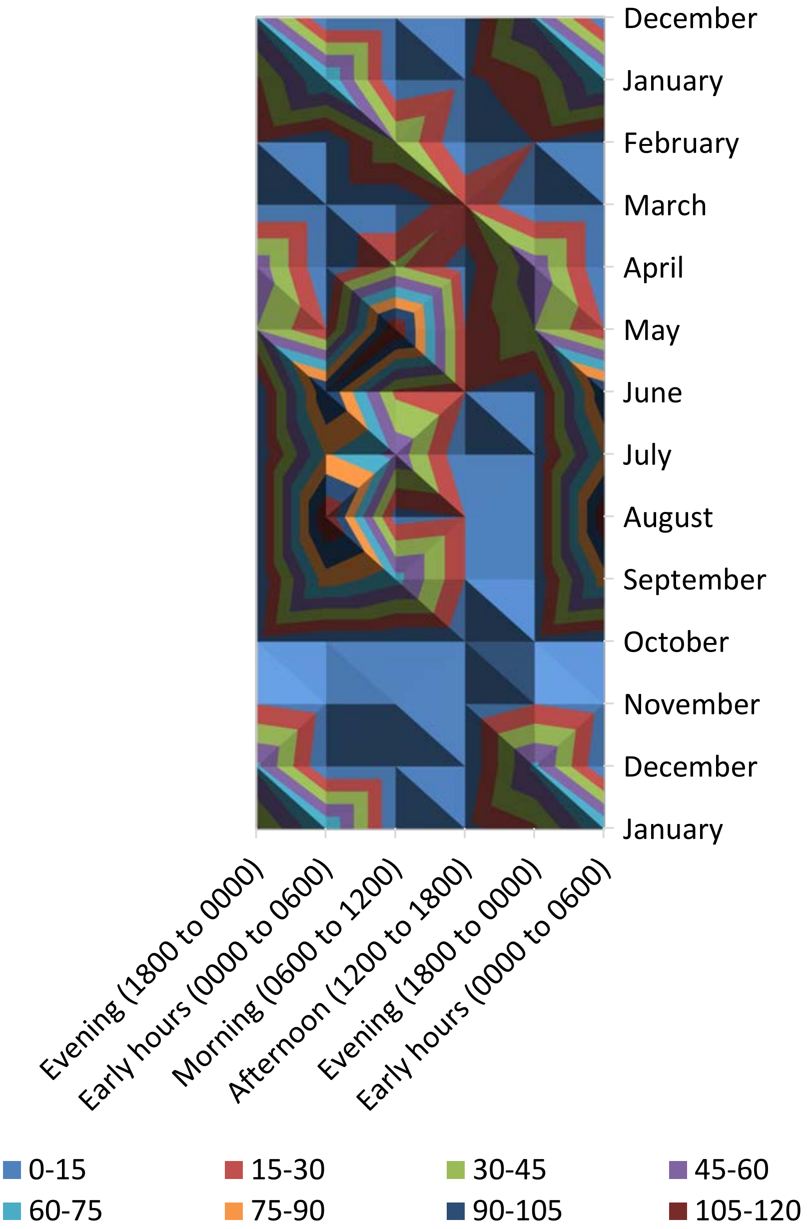


Calculated holding time per unprimed observation is shown in Figure 74 for each month and each day quadrant. The longest estimated holding time was in the early hours (midnight to 0600) in August, with a median calculated average holding time of 386 minutes. Other episodes in the early hours also had long median holding times (January at 75 minutes, June at 105 minutes, July at 76 minutes, and September at 84 minutes median calculated average holding time). As shown above, however, very few aircraft arrive at Mildura in the early hours. May had the highest estimated holding times in the morning quadrant (0600 to 1200) (median 165 minute average calculated holding).

In July mornings when unprimed observations were at a peak, expected holding times were lower but still significant, with more than half of episodes being more than 55 minutes.

Expected holding times can also be seen to carry across the summer months from December to April, with longer holding times in the evenings in December moving to even longer holding times in January in the early mornings, and then progressing to lower peak holding times in February in the mornings, March during the afternoon and April in evenings. This is shown as a diagonal line starting at the top left of Figure 74 through to April evenings.

Figure 74: Median calculated average holding time following arrival during unprimed observations below landing minima by month and quadrant of day for forecast retrieval between 0 and 2 hours prior to arrival 2009 to 2013



Duration and effect of unprimed observations

Figure 75 shows the number of weather episodes with unprimed observations below the landing minima by the duration of all observed conditions below the landing minima. This indicates the overall period of time that an aircraft could not land during episodes when there were both unprimed and no unprimed observations below the landing minima.

Although many observed conditions had durations of half an hour or less (both unprimed and primed), more than half had conditions below the landing minima for more than 75 minutes (cumulative percentage lines in Figure 75 also shows the proportion of weather episodes that contained unsafe conditions (purple columns) to those when conditions were completely forecast (transparent columns) for each duration of the observed conditions below then landing minima.

When compared to episodes with no unprimed observations below the landing minima, there were relatively more unprimed weather episodes between 15 and 45 minutes duration, and relatively less of these events around 90 minutes duration and longer below the landing minima.

Figure 75: Duration of all observed conditions below the landing minima by number of weather episodes with unprimed observations for various TAF retrievals times between zero to 2 hours prior to arrival 2009 to 2013

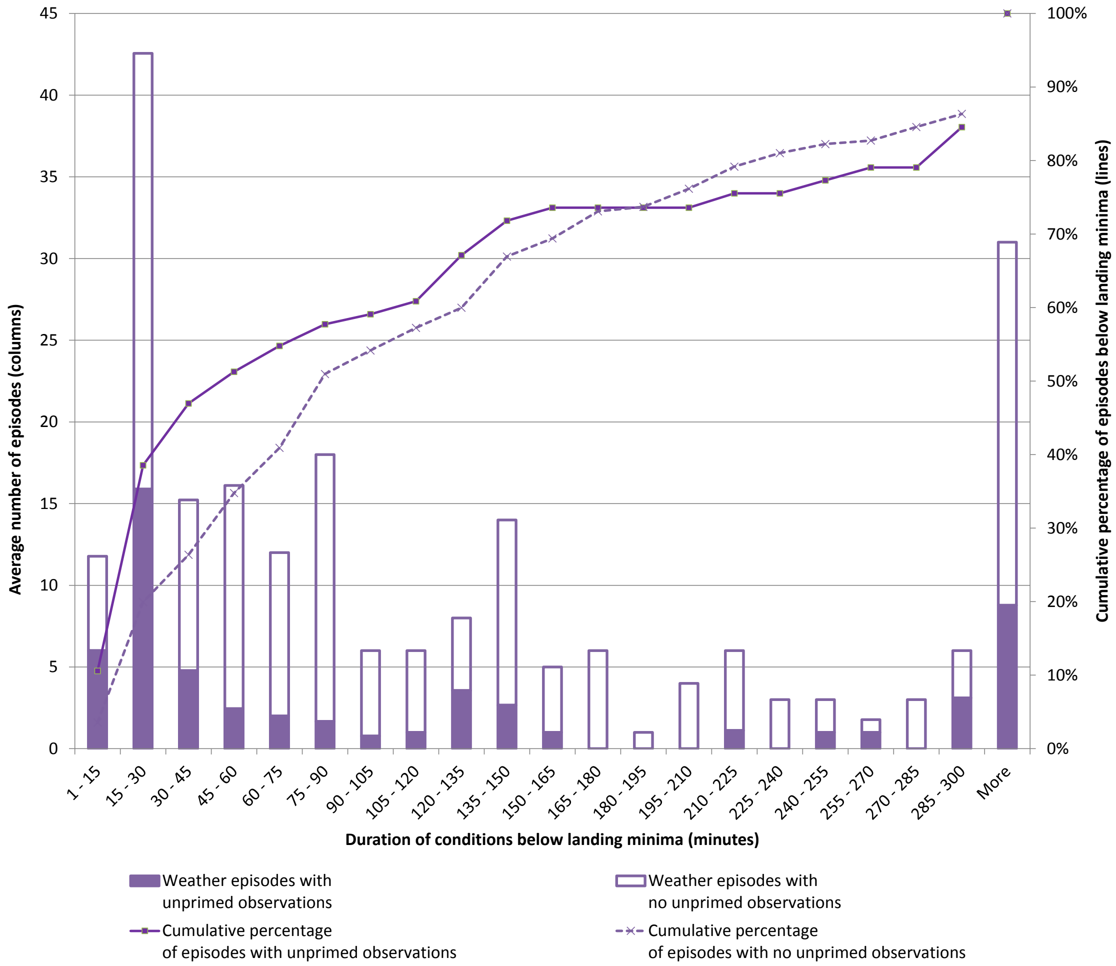
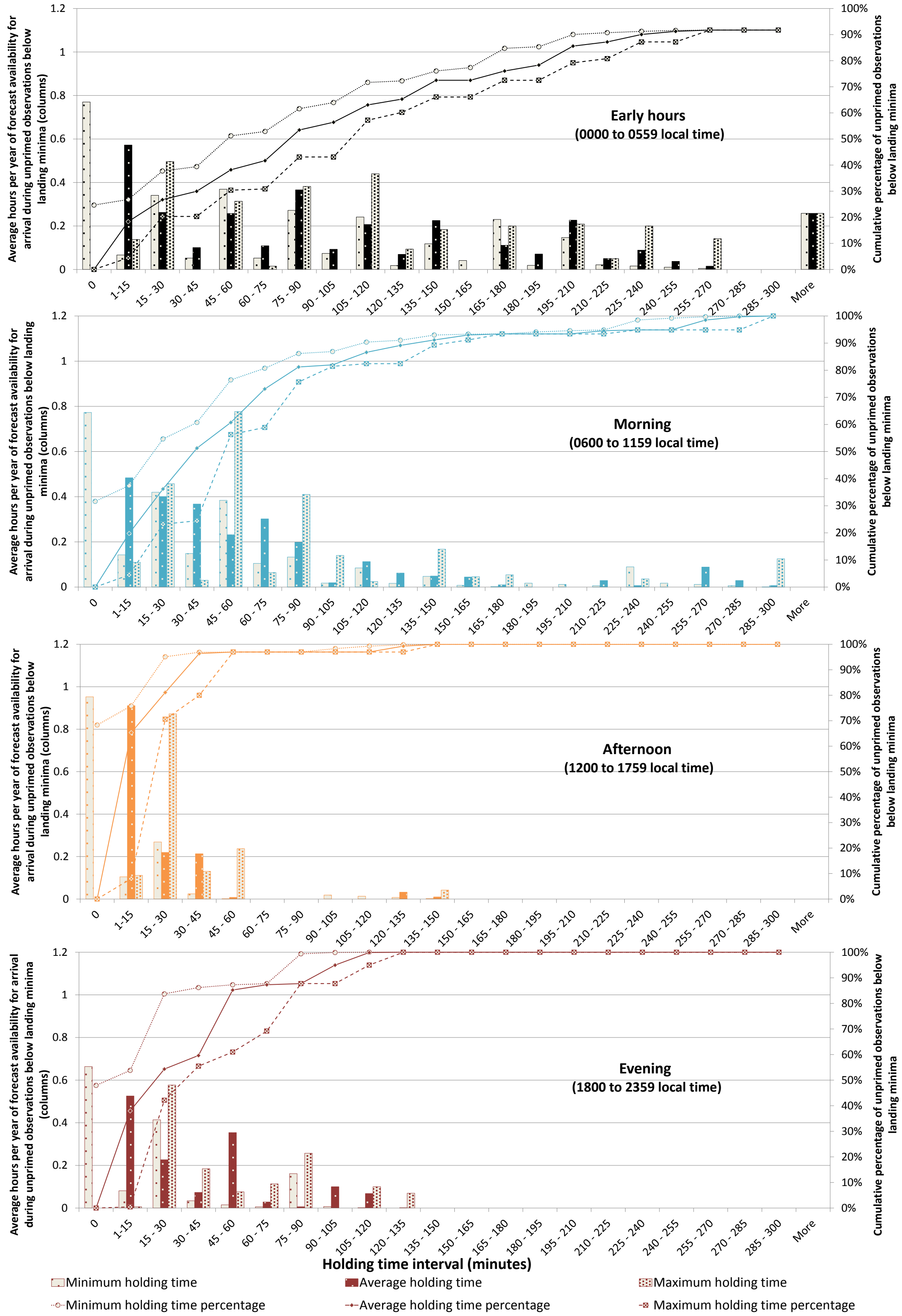


Figure 76 displays the calculated holding time durations on the horizontal axis, showing hours of unprimed observations per year. Each graph displays one of the four daily quadrants. The columns show the average, minimum and maximum calculated holding times. While the below text focuses on average holding time, the other columns can be reviewed to see the range from the best case scenario (minimum holding time) to the worst case scenario (maximum holding time).

The top chart, displaying early hours, shows calculated average holding times have a much longer range than at other times of the day, with 58 per cent of the duration of unprimed arrival periods had an average holding times longer than 75 minutes. For the morning quadrant, 64 per cent of unprimed arrivals were longer than 30 minutes, and 49 per cent were longer than 45 minutes. The afternoon calculated holding times were generally quite short. Sixty-five per cent of the afternoon holding times were up to 15 minutes, and there were very few periods greater than an hour. The evening holding times were slightly more spread out, with 46 per cent of unprimed arrival times being longer than 30 minutes.

Figure 76: Distribution of hours per year of unprimed observations by average, minimum and maximum calculated holding times, for TAF retrieval times from zero to 2 hours prior to arrival 2009 to 2013



Forecast retrieval time comparisons

The analysis above was based on the combined effect of retrieval times between zero and 2 hours prior to arrival, averaged every 15 minutes. In this section, unprimed observations below the landing minima are analysed for every retrieval time (in 15 minute intervals) up to 6 hours before arrival.

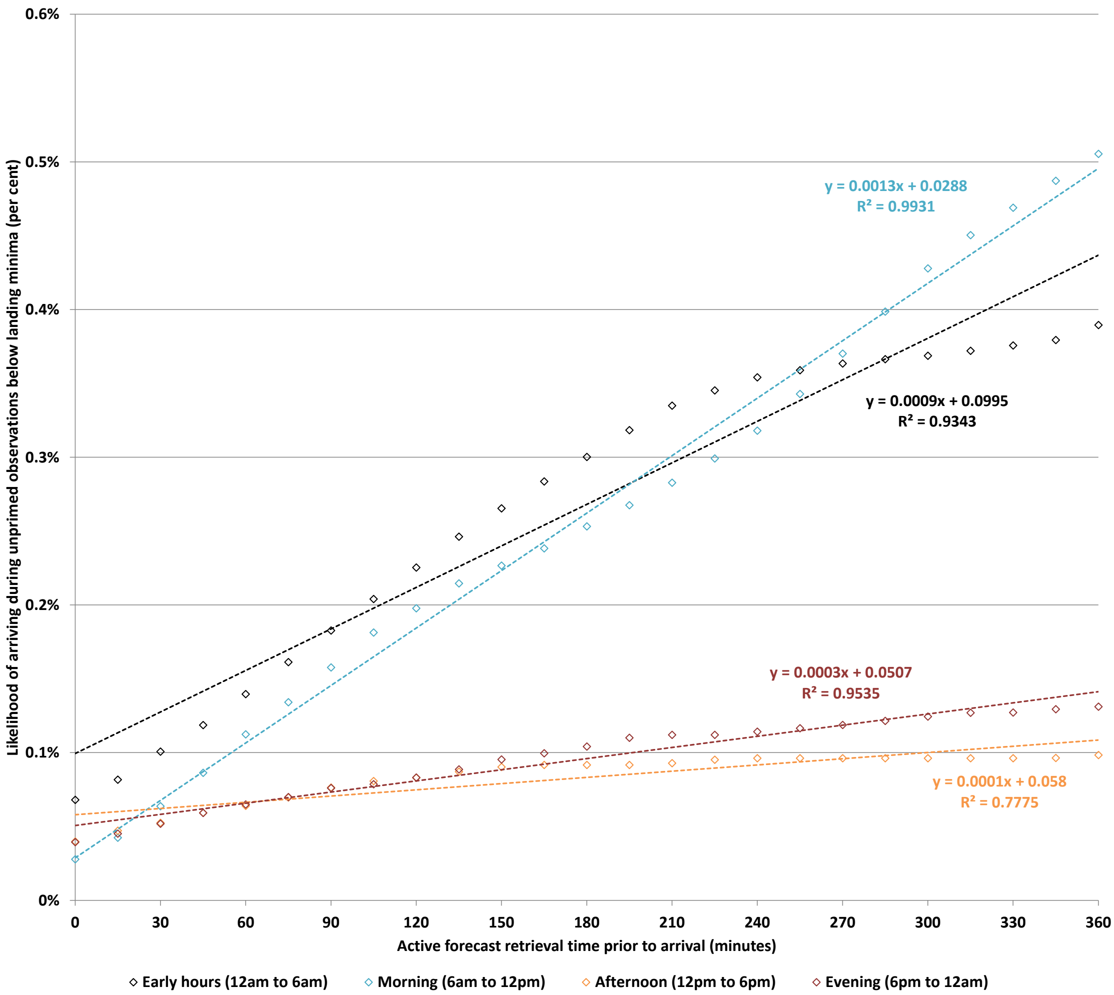
Figure 77 shows the number of hours of unprimed observations per year as a percentage of all time (any type of observed weather), for each daily quadrant, for retrieval times up to 360 minutes (6 hours). It shows that in the early hours and morning quadrants, retrieving a forecast further before arrival will increase the likelihood of arrival during unprimed observations below the landing minima. For the mornings (0600 to 1200), retrieving a forecast 60 minutes before arrival results in a 0.1 per cent chance of arriving during unprimed observations. This increases to 0.51 per cent chance if the forecast is retrieved 6 hours before arrival. That is, if a company flew a single aircraft to Mildura every day of the year, and always arrived in the mornings, they are likely to arrive with unprimed observations below the landing minima:

- about once every 2.4 years if they retrieve forecasts 1 hour before arrival
- about once every 17 months if they retrieve forecasts 2 hours before arrival
- about once every 13 months if they retrieve forecasts 3 hours before arrival
- about once every 11 months if they retrieve forecasts 4 hours before arrival
- about once every 8 months if they retrieve forecasts 5 hours before arrival
- about once every 6 months if they retrieve forecasts 6 hours before arrival.

The larger overall values and gradient in the early hours and morning are due to both a larger number of observations below landing minima and the relative proportion of unprimed observations to the overall observations below landing minima.

From the perspective of operational decision making, this shows that in the early hours and morning, it is relatively more important that forecasts are retrieved at the latest possible time (before the point of no alternate) prior to arrival. However, in the afternoon and evening, the forecast retrieval time prior to arrival has minimal impact.

Figure 77: Likelihood of arriving during unprimed observations below landing minima for TAF retrieval times prior to arrival (0 to 360 minutes) 2009 to 2013[66]



Analysis by time of day above (Figure 66) showed that 1000 to 1100 was a particular common time for unprimed observations below the landing minima (0.7 hours per year) and coincided with peak aircraft arrivals at Mildura. Applying the same regression equation as above to 1000 only, the above example (a company flies to Mildura once a day and arrives between 1000 and 1100), and the chance of retrieving an unprimed observations below the landing minima is:

- about once every 13 months if they retrieve forecasts 1 and 2 hours before arrival
- about once every 10 months if they retrieve forecasts 3 hours before arrival
- about once every 9 months if they retrieve forecasts 4 or more hours before arrival.

Figure 78 below shows the percentage of unprimed observations as a proportion of all observations below the landing minima for arrival after retrieving a forecast between 0 and 360 minutes (6 hours) prior to arrival. In contrast to Figure 77 which shows the likelihood of arriving during an unprimed observation, Figure 78 shows the reliability of forecasts when observations are below the landing minima.

At the time of arrival (retrieval time of 0), the proportion of observations below the landing minima that were unprimed were the highest in the afternoons and evenings, with 6.4 per cent and 6.1 per cent respectively. In comparison, mornings were much lower at 1.2 per cent. In the early hours 4.3 per cent of observations were unprimed at the time of arrival. The relatively high percentage of

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66 R^2 shows the goodness of fit (percentage of variation explained) of the linear regression line to the scatter plot.

unprimed observations in the afternoons and evenings can be explained mainly by shorter term thunderstorm activity and dust related phenomena, as shown in *Characteristics of unprimed observations* on page 132.

The early hours had the most rapid increase in the percentage of unprimed observations as the duration of time between forecast retrieval and arrival became longer. The early hours' quadrant proportion of unprimed observations increased 4.8 per cent for each additional hour the forecast was retrieved prior to arrival up four hours, slowing to 1.5 per cent up to six hours. The percentage of unprimed observations in the morning had the second highest gradient, increasing 3.4 per cent each hour up to six hours prior to arrival.

Unprimed observations in the afternoons and evenings increased at a relatively slower rate, resulting in a larger proportion of unprimed observations in the morning for forecast retrievals prior to arrival greater than 4 hours 30 minutes for afternoons and 5 hours 30 minutes for evenings.

The proportion of unprimed observations in the afternoon hours was the most stable for forecast retrievals between 1 and 6 hours prior to arrival, increasing about 1.4 per cent each hour.

This graph shows that for different times of day, the ability to predict when conditions will fall below the alternate minima is more difficult by varying degrees the longer the time prior to the observation.

Figure 78: Hours of unprimed observations as a percentage of all observations below the landing minima for TAF retrieval times prior to arrival (0 to 360 minutes) 2009 to 2013[66]

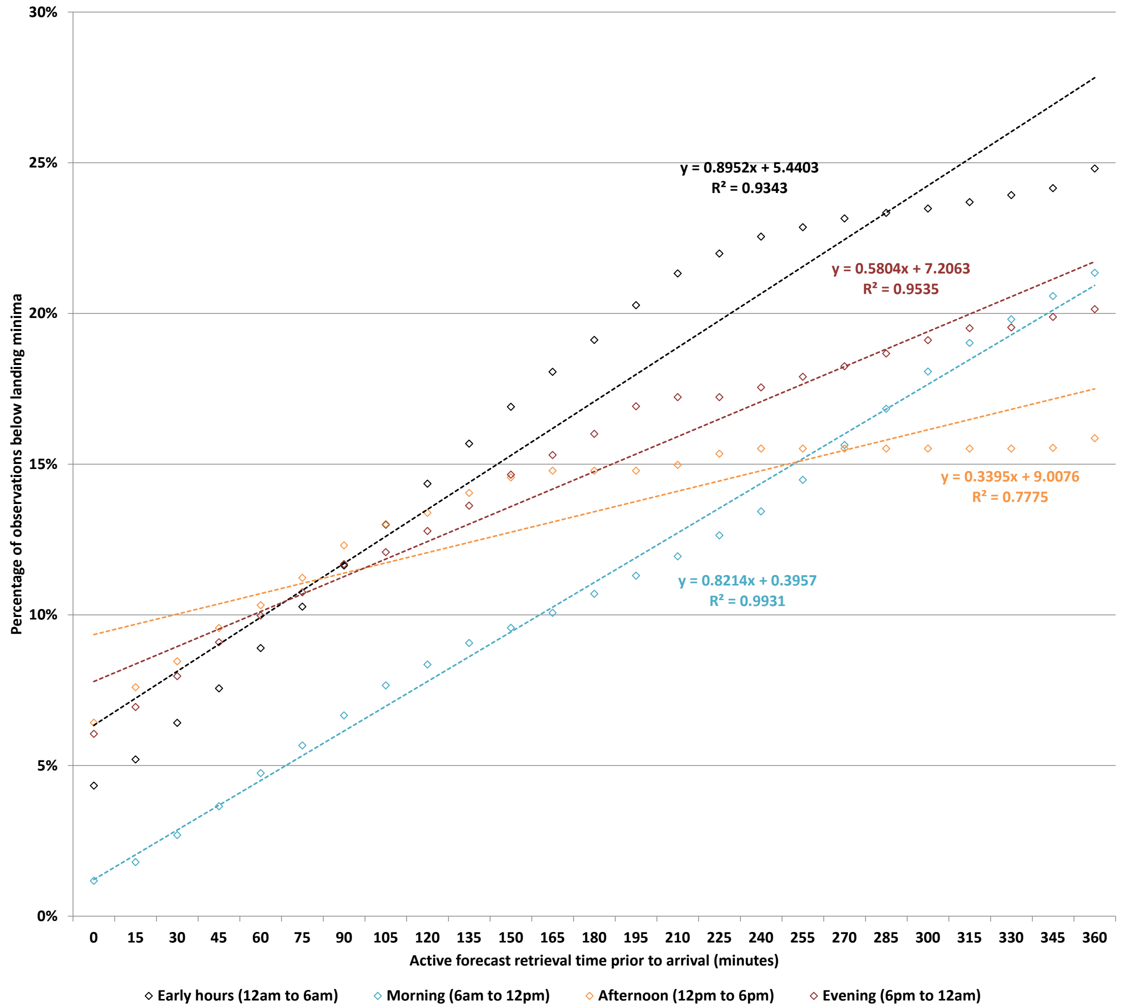


Figure 79 shows the variation in the hours of unprimed observations below the landing minima for arrival at different times of day for varying forecast retrieval times. The forecast retrieval times from 0 to 1 hour, 1 to 2 hours, and 2 to 3 hours prior to arrival were averaged every 15 minutes.

Although the general distribution is similar between each retrieval time group, there were some notable differences.

Overall, as shown in Figure 77 above, there is a lower likelihood of arriving during an unprimed observation as the retrieval time approaches the arrival time.

The largest differences in unprimed observations as forecast retrieval time increased occurred in the early hours and morning.

The largest variation between forecast retrieval times was between 0300 and 0500. For 0400 to 0500, an unprimed observation after a forecast retrieval 1 to 2 hours prior to arrival was 3.1 times more frequent than retrieving a forecast 0 to 1 hour prior to arrival. Furthermore, unprimed observations after forecast retrievals 2 to 3 hours prior to arrival were 1.9 times more frequent than those retrieved 1 to 2 hours prior between 0400 and 0500.

There was also a notable increase of unprimed observations with longer forecast retrieval times prior to arrival between 0600 and 0700. These occurred 2.3 times more often at 1 to 2 hours than 0 to 1 hours prior to arrival, and 1.5 times more at 2 to 3 hours than 1 to 2 hours prior to arrival.

Unprimed observations exists between 1000 and 1200, also had a notable increase as the time between forecast retrieval and observations becomes longer.

Figure 79: Unprimed observations for ranges of forecast retrieval times prior to arrival and number of aircraft arrivals per year[67] by hour of arrival (local time) 2009 to 2013

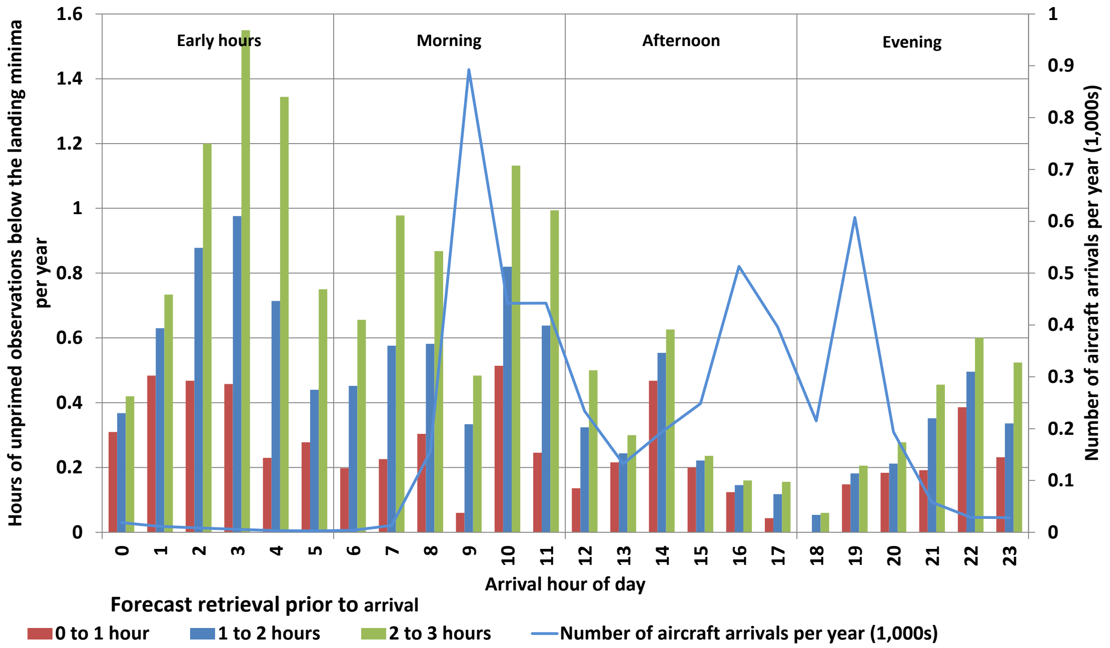


Figure 80 shows the percentage of unprimed observations as a proportion of all observations below the landing minima. Figure 79 and Figure 80 show similar information to Figure 77 and Figure 78 above, in that the former of each pair indicates the overall likelihood of arriving during an unprimed observation given a forecast retrieval time, and the latter indicates the reliability of the forecasts when observations were below the landing minima.

The general shape of Figure 80 is the same as Figure 67 on page 115 which shows the average proportion of unprimed observations to all observations below landing minima for forecast retrievals between 0 and 2 hours prior to arrival.

The largest increases in the proportion of unprimed observations as forecast retrieval times increased were in the early hours, especially between 0200 and 0400.

[67] This was based on hourly aircraft arrivals data between 2010 and 2013

In the morning and early afternoon, from 1000 to 1300, the proportion of observations below the landing minima that were unprimed from 0 to 1 hour to 1 to 2 hours was 1.7 times greater for 1000 to 1100, 3.1 time greater for 1200 to 1300, and 2.8 times higher for 1100 to 1200. Retrieving a forecast between 1 to 3 hours before arrival, one in every three minutes of observations below the landing minima were unprimed for arrivals between 1100 and 1200 (1 in every five minutes for 1000 to 1100). As seen above, this time of day also corresponds to the time of both elevated observations below the minima and aircraft arrivals.

Three retrieval time group trends were identified around the time of the day that the peak percentages of unprimed observations compared with all observations below landing minima were seen:

- The morning increase is shifted later in the day from 1000 toward 1200 for each later retrieval time group.
- The early hours increase is also shifted later in the day from midnight toward 0300 for each later retrieval time group.
- The evening increase is shifted earlier in the day from 2200 toward 2100 for each later retrieval time group.

Shifts toward the later in the day with increasing retrieval time prior to arrival in Figure 80 are likely to be driven by the retrieval time (relative to arrival) and the subsequent reaction time to unfolding weather episodes by forecasters, and may indicate that there is difficulty in predicting the end of episodes at this time. Shifts toward earlier in the day possibly indicate problems with determining when these weather episodes will start.

Figure 80: Percentage of total time below landing minima for unprimed observations for ranges of forecast retrieval times prior to arrival and number of aircraft arrivals per year[67] by hour of arrival (local time) 2009 to 2013

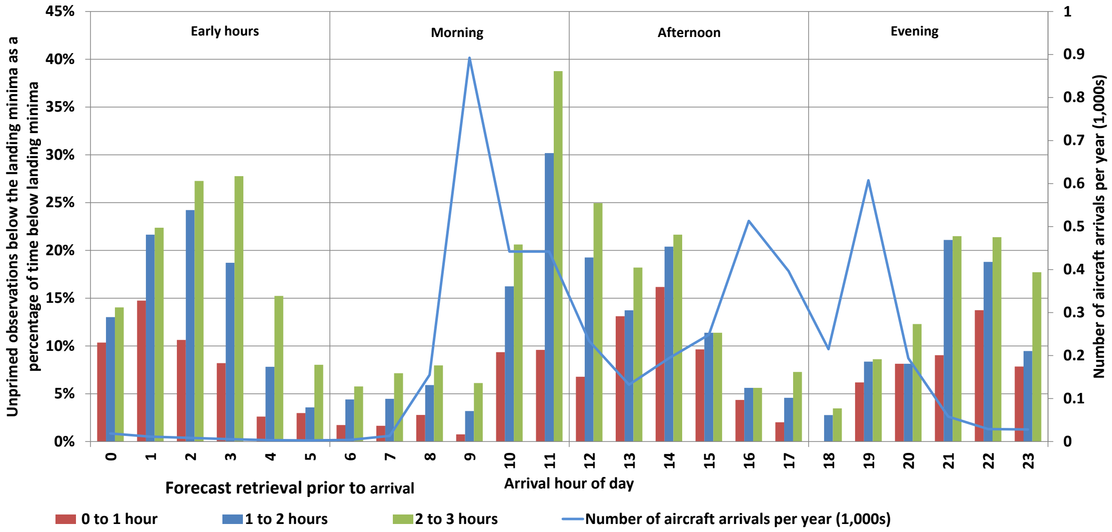


Figure 81 shows the variation in the holding time medians by quadrant of day for forecast retrieval time prior to arrival with unprimed observations below the landing minima. Additionally, it shows the probable number aircraft affected per year for each retrieval time.

The difference between the minimum, average and maximum median holding times is relatively stable for retrieval times greater than 180 minutes up to 360 minutes prior to arrival in each quadrant of the day. As also shown in Figure 76 on page 124 and Figure 68 on page 116, the early hours have the longest holding times with the largest variation for average forecast retrieval times 0 to 2 hours prior to arrivals, however, holding time in mornings become longer on average for forecast retrieval times beyond 2 hours prior to arrival, with an overall average of 49 minutes. The afternoon and evenings had very similar median holding times, with an average of 15 and 18 minutes respectively for most forecast retrieval times.

The averaged median estimated holding time for early hours was 36 minutes averaged for simulated forecast retrievals 0 to 6 hours prior to arrival.

Figure 66 and Table 7 on page 113 above showed that mornings had the largest number of expected aircraft arrivals during unprimed observations (2.4 aircraft affected per year for forecast retrievals averaged between 0 and 2 hours prior to arrival). In contrast to Figure 66, the change in expected unprimed aircraft arrivals affected by simulated forecast retrieval time can be seen in Figure 81.

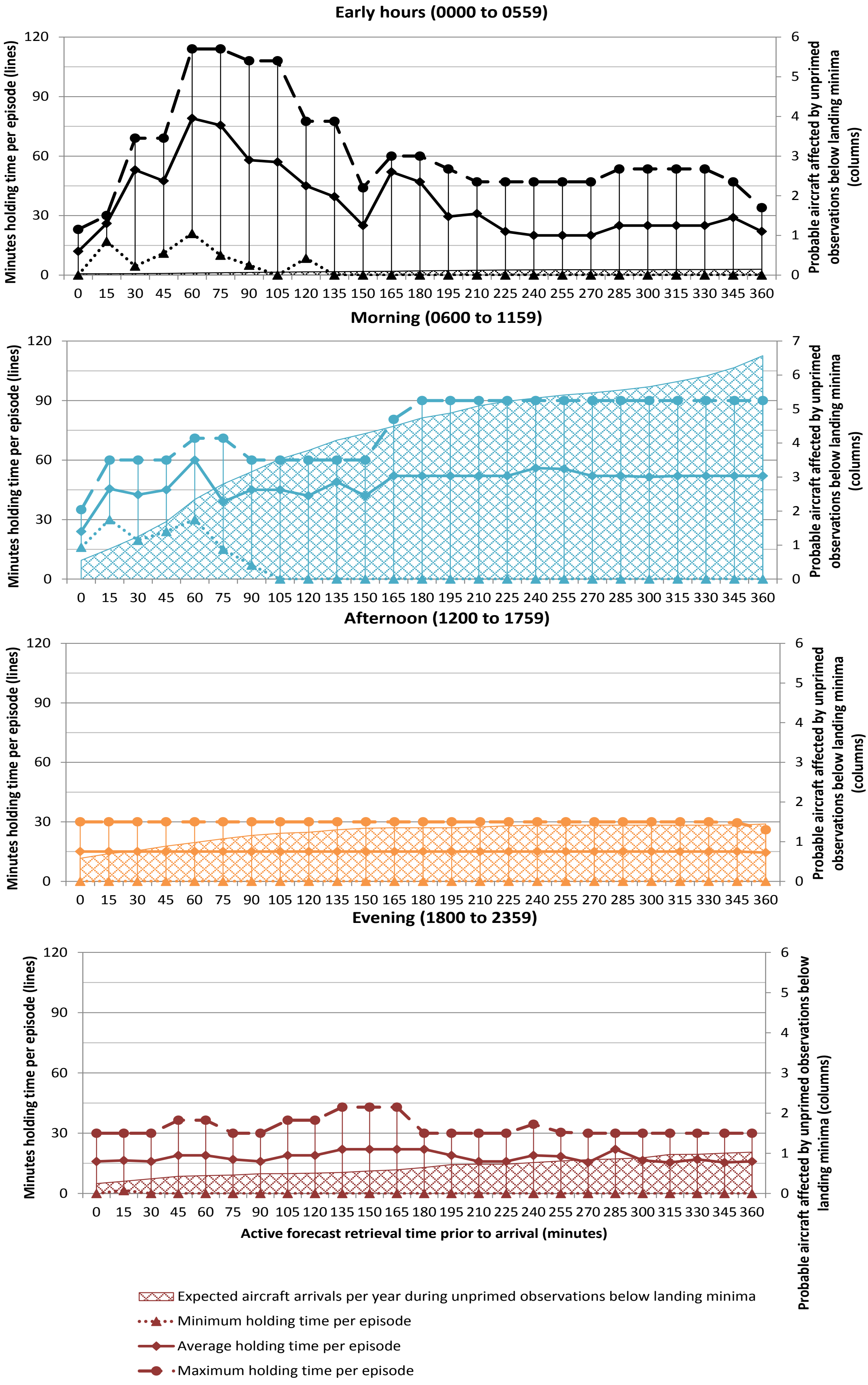
In the morning, a substantial climb in the number of expected unprimed aircraft arrivals can be seen in Figure 81 from less than 1 per year, up to 3.2 per year if all forecast retrievals were performed 90 minutes prior to arrival. A steady increase continued with an expected 6.6 aircraft affected per year if all forecast retrievals were performed 6 hours prior to arrival in the morning.

The afternoons and evenings were similar in the probable number of aircraft affected by forecast retrieval time. Afternoons plateaued at around 1 aircraft affected every 9 months at forecast retrievals 2 hours prior to arrival. Evenings exhibited a small but steady increase from one unprimed aircraft arrival every four years to 1 aircraft arrival per year.

In the early hours, only 1 aircraft is expected to be affected at most every 10 years on average between the hours of midnight and 0600. However it is important to note that if an aircraft were to arrive during this period, there is a higher likelihood of being exposed to longer periods of holding.

Based on the changes in calculated aircraft affected by unprimed observations, it is more important during the morning quadrant for pilots to retrieve a forecast as close as possible to their arrival into Mildura. It should be noted that as the median calculated average holding time was 48 minutes, this means that half of the calculated holding times will be longer than 48 minutes.

Figure 81: Median holding time (average, minimum and maximum) and expected aircraft arrivals during unprimed observations following simulated TAF retrieval times between zero and 6 hours prior to arrival 2009 to 2013



Characteristics of unprimed observations at Mildura

Forecast timing characteristics

Unprimed observations below the landing minima were categorised by their chronological nature as shown in Figure 82. These are shown for unprimed observations averaged for forecast retrieval times between zero and 2 hours prior to arrival.

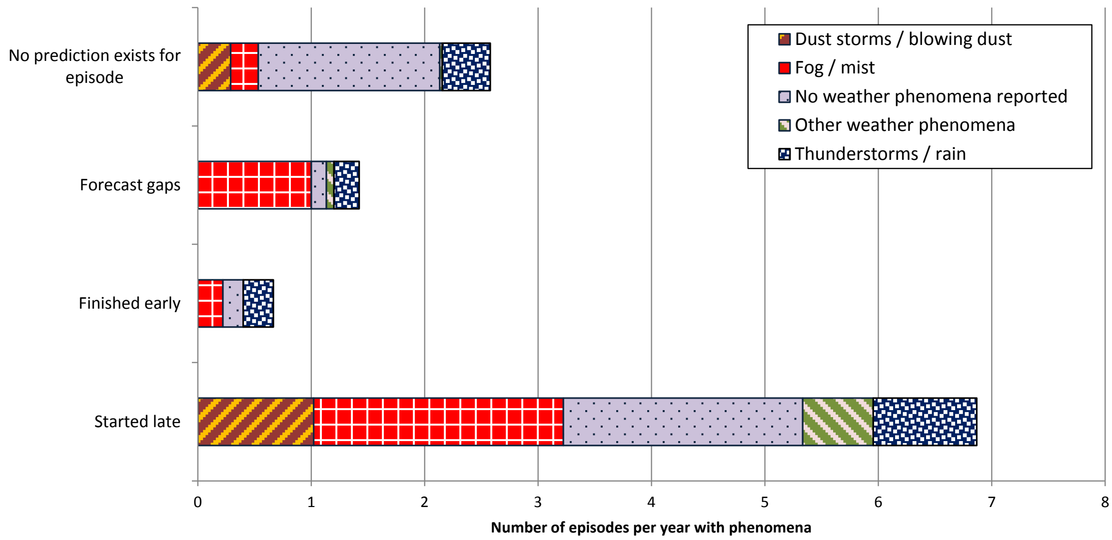
Forecasts of the observed conditions that started late were the most common (about 7 episodes per year). These were episodes where conditions below the alternate minima were forecast to commence after a period of unprimed observations. This may be the result of either a new forecast being released or a time-based change existing within the original forecast. Thirty-two per cent of these starting late episodes were for fog and/or mist phenomena. However, all other weather phenomena were also associated with episodes that started late.

There were about 5 episodes every 2 years where no forecast below the alternate minima was present for the duration of the observations below the landing minima. Most of these episodes did not have the weather phenomena reported. However, it can be seen that, relative to the other reasons for unprimed observations, fog/mist (the most common weather phenomena) were uncommon when there was no prediction for the weather episode. In addition, non-predictions made up only 7 per cent of episodes with unprimed fog and mist.

Gaps in the forecasting were the next most common type of unforecast observation (about 3 every 2 years), resulting mostly from fog/mist.

Forecasts finishing early were the least common reason, divided between fog/mist, thunderstorms/rain and no reported phenomena.

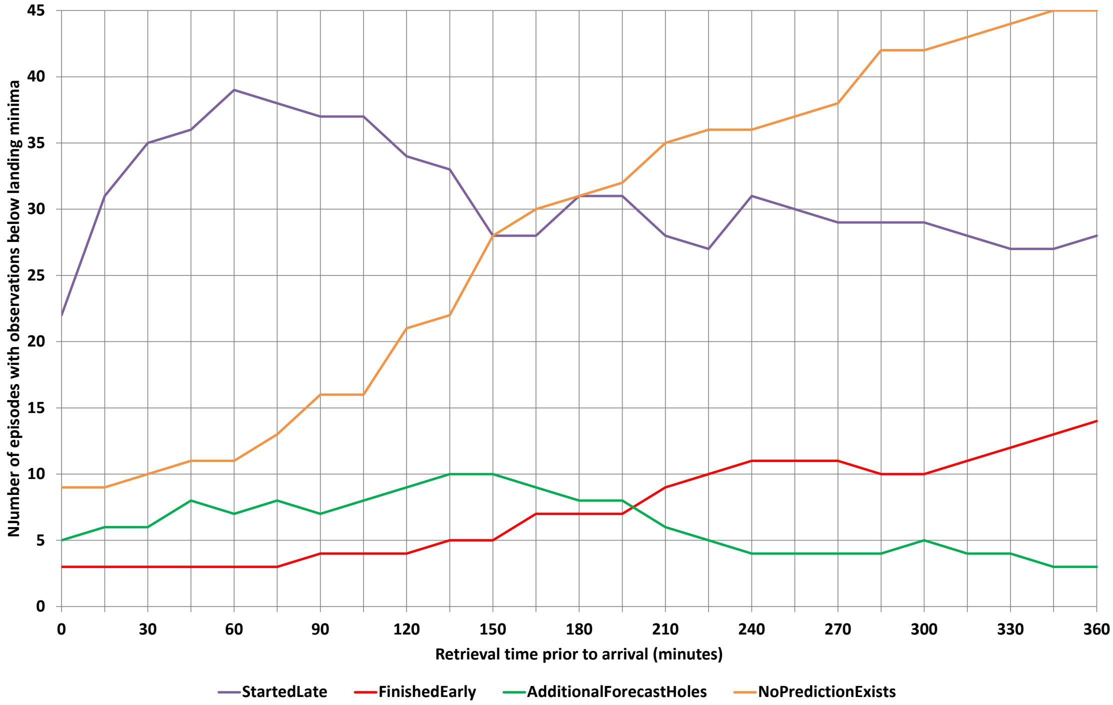
Figure 82: Number of episodes with unprimed observations below the landing minima by forecasting characteristic averaged for TAF retrieval times from 0 to 2 hours prior to arrival 2009 to 2013



Thunderstorms were relatively evenly distributed across the different forecasting characteristics, making up 40 per cent of episodes finishing too early and between 13 to 16 per cent of the remaining categories. The majority of unprimed episodes with reported dust storms and blowing dust (all below the landing visibility minimum) were preceded by unprimed observations below the landing minima (started late).

While Figure 82 above shows the most common reasons for unprimed observations between zero and two hours before arrival, Figure 83 shows the same reasons extending out to 6 hours. Figure 83 shows that while it was more common for episodes to have late primed observations (started late) than having no primed observations at all in the first two hours, after two hours before arrival, the number of observations below the landing minima that were not predicted at all continue to increase (to 9 per year 6 hours before arrival) to be more common than starting late beyond 2.5 hours prior to arrival.

Figure 83: Number of episodes with unprimed observations below the landing minima (for each retrieval time prior to arrival) by forecasting characteristic 2009 to 2013 (Note: Sum of characteristics is greater the total number of episodes due to multiple categories applying to some episodes.)



Episodes starting late were the most common 60 minutes before arrival. Forecasts that finished early gradually increased after the first hour before arrival approaching 3 episodes per year if all TAFs were retrieved 6 hours prior to arrival. Episodes with gaps in the forecasting (forecast holes) peaked at around 2 episodes per year at 2.5 hours prior to arrival before decreasing out to 6 hours.

The peak in episodes starting late is probably related to responses to observations below or trending below the observed alternate minima that were formerly not forecast. This is based on almost all of the periods of unprimed observations ceasing due to the release of amended TAFs. This provides an indication of the systemic reaction time, and is shown for relevant episodes in Figure 84.

Figure 84: Primed forecast release times relative to first observation below landing minima in each weather episode (Predictive system recovery and reactive system recovery) and unprimed episodes with no recovery by observed weather phenomena, Mildura Airport 2009 to 2013

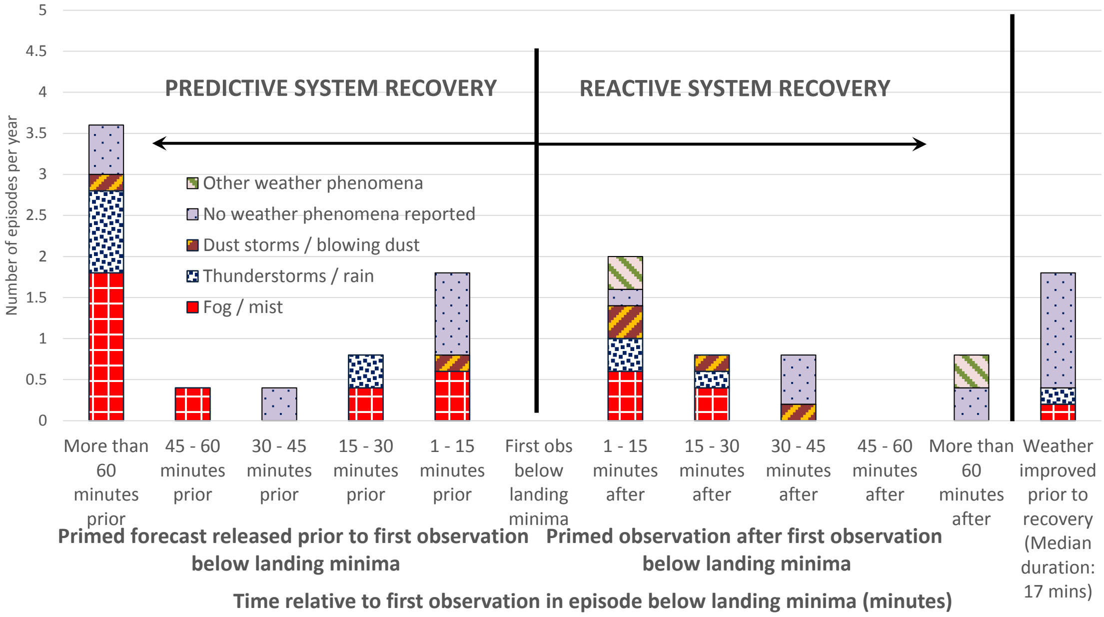


Figure 84 shows episodes per year where unprimed TAFs were active prior to or following an observation below the landing minima, however, a subsequent forecast was released predicting conditions below the alternate minima (Hit (H1) and Buffer (B2) in Figure 6). The labels 'predictive' and 'reactive' system recovery refer to relative timing of the forecast correction.

Episodes relating to reactive scenarios are shown to the right of the first observations below landing minima in Figure 84, and indicate situations where weather below the landing minima has occurred, followed by the system recovering with a primed observation. This can be considered as the reaction time to unprimed observations below the landing minima. This shows that for about five episodes every 2 years (22 in total), the system takes longer than 15 minutes to become primed following unprimed observations below the landing minima. This is in addition to around least two episodes every year on average that no prediction exists as shown in Figure 82.[68]

In most cases, reactive system recovery was in the form of an amended TAF release (19 out of 22 episodes between 2009 and 2013). The other three episodes consisted of two with forecast segments predicting conditions later than observed and one routine TAF release.

The median reaction time (taking all episodes on the right of 'First obs below landing minima') was calculated to be 16 minutes.

Predictive recovery scenarios are where an unprimed forecast exists, however a new (generally amended) forecast is released predicting conditions below the alternate minima (providing warning of unsuitable landing conditions). These are shown to the left of the 'First obs below landing minima' label in Figure 84.

Predictive recovery scenarios occur about seven times per year (36 total). Similarly to the reactive recovery scenarios, systemic recovery was in the form of amended TAF release (33 out of 36 episodes), with 3 routine TAF releases.

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68 Note the calculations in Figure 84 are based on fixed retrieval times, resulting in slight differences with those presented in Figure 82 (based on averaging).

Landing and alternate minima criteria for primed and unprimed observations

The red columns in Figure 85 shows the hours per year the observed weather at Mildura was below each of the five landing minima criteria (both unprimed (dark red) and primed (light red)). For the visibility and ceiling criteria, it also shows observations above the landing minima but below the alternate minima that were unprimed (dark blue) and primed (light blue).

Referring to Figure 6 on page 26, these are the same as the categories ‘Miss’ for unprimed and two categories ‘Hit (H1)’ and ‘System buffer’ (B1) for primed. For the visibility and ceiling criteria, it also shows observations above the landing minima but below the alternate minima that were unprimed (dark blue) and primed (light blue), again from Figure 6, this equates to ‘System buffer (B2)’ for unprimed and ‘Hit (H2)’ and ‘Partial Hit (PH)’ for primed. A breakdown of the totals of each of these categories is shown in Figure 63 on page 110.

Nine per cent of all visibility below the landing minima was unprimed, and the ceiling landing minima criterion was unprimed six per cent of the time. For thunderstorms, only one in 25 minutes were unprimed.

For both the visibility and ceiling criteria, there were more observations between the alternate and landing minima than there were observations below the landing minima, both primed and unprimed. In addition, 21 per cent of observations were unprimed for visibility, but only 8 per cent were unprimed for ceiling. Because the existence of thunderstorms is the only criteria (for both landing and alternate minima), and because the crosswind and tailwind had the same thresholds applied for both the alternate and landing minima, these criteria not have did not have any observations between the alternate and landing minima.

Figure 85: Hours per year for observed criteria below landing minima and below alternate minima, primed and unprimed for simulated TAF retrievals averaged 0 to 2 hours prior to arrival, Mildura Airport 2009 to 2013.

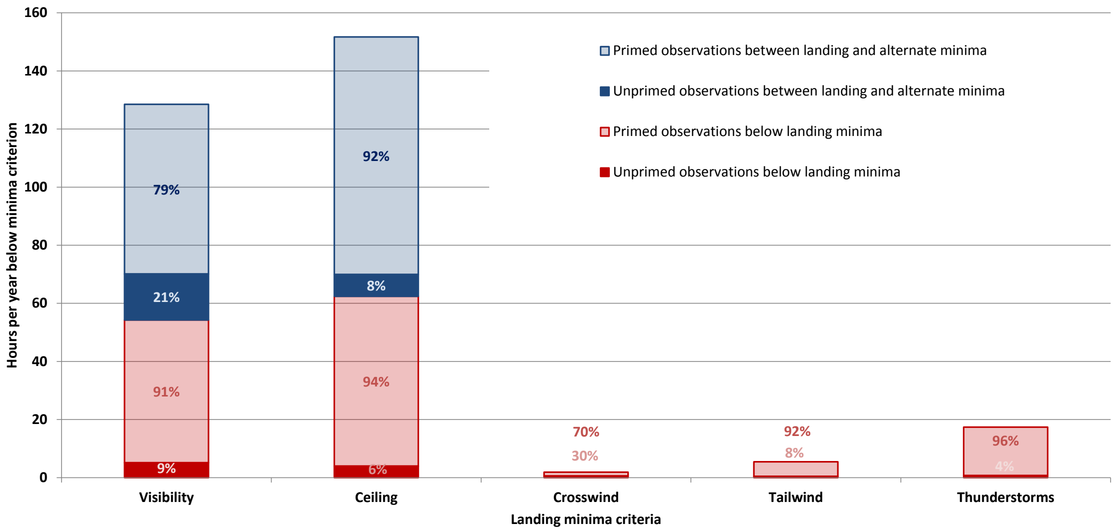
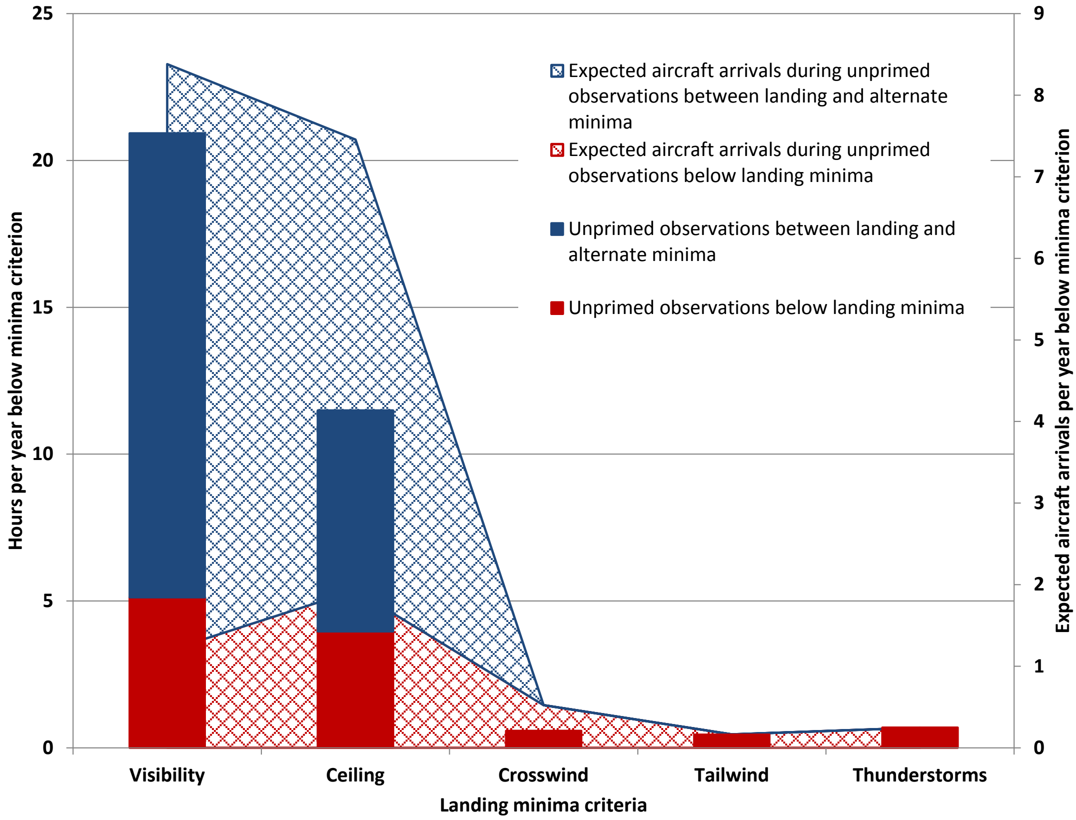


Figure 86 shows only unprimed observations along with the number of expected aircraft arrivals during these times each year. There were about 5 hours per year of unprimed observations below the visibility landing minima, 4 hours under the ceiling minima. Unprimed thunderstorms, crosswind and tailwind ranged between 27 and 42 minutes per year. The unprimed visibility observations affected slightly more than 1 aircraft per year, while the unprimed ceiling observations affected slightly close to 2 aircraft per year. Thunderstorms 1 aircraft every four years, unprimed crosswind about 1 aircraft every 2 years and tailwind (resulting from visibility and / or ceiling below minima on the reciprocal runway), 1 aircraft every 6 years.

For unprimed observations between the alternate and landing minima, there were 16 hours for the visibility criterion each year, and 7.5 hours a year for the ceiling criterion. It is important to note that although unprimed, aircraft could still land in these conditions. Unprimed visibility between the landing and alternate minima was encountered by about 7 aircraft each year, while ceiling between the two minima were encountered by 5 aircraft each year.

Figure 86: Hours per year for unprimed observed criteria below landing minima and below alternate minima for simulated forecast retrieval time averaged 0 to 2 hours prior to arrival. Hatched area shows expected aircraft arrivals during unprimed conditions, Mildura Airport 2009 to 2013



Time of day

Minima criteria

The overall effect from time on day (discussed above in the *The effect of* forecasts on aircraft operations - Mildura Airport chapter) is broken down into the five criteria used for the landing minima.

The peak combined primed observations below the landing minima seen in Figure 66 (page 113) around 0700 can be seen in to driven mostly by the visibility criterion with almost 9 hours a year at 0700 (Figure 87), and the ceiling criterion with 7 hours a year at 0700 (Figure 88). However, unprimed observations vary more in the morning quadrant, peaking at 0800 for visibility but at 1000 for ceiling. The combined peak of unprimed observations (seen in Figure 66) at 1000 was mostly driven by unprimed ceiling below the landing minima. Although observations of the ceiling criterion below the landing minima at 1000 were not common (3.5 hours per year), the proportion that were unprimed was relatively large (19%). In addition, the peak aircraft affected at 1000 was mostly driven by unprimed observations below the ceiling minima (Figure 88).

In the afternoon unprimed observations are mostly from the thunderstorm criterion from 1600 to 1900 (Figure 91), visibility from 1400 to 1600, and crosswinds from 1200 to 1700 (Figure 90). Slightly more aircraft were expected to arrive during unprimed crosswind in the afternoon, collectively 1 aircraft arrivals every 3 years. In the evening, visibility was the main source of unprimed observations, including those affecting aircraft. Although low in time, evenings from 2100 to 2300 saw the thunderstorm criterion unprimed about a quarter of the time.

Overnight, visibility was accounted for most of the unprimed observations followed by unprimed ceiling, however, virtually no aircraft were expected to arrive during these times (Figure 87 and Figure 88). From 0100 to 0400, about 30 per cent of visibility below the landing minima was unprimed.

Observations between the landing and alternate minima (blue columns) were more common for ceiling than visibility in the mornings, especially after 0900. However, visibility had a slightly higher proportion of unprimed observations between the landing and alternate minima in the morning (about 17 per cent of visibility, and 11 per cent of ceiling were unprimed). It is important to remember that although unprimed, aircraft could still land when the observations were between the landing and alternate minima. The most prominent expected aircraft arrivals during unprimed observations between the landing and alternate minima were at 0900 for ceiling (about 5 aircraft arrivals every 2 years), and also 0900 for visibility (about 7 aircraft arrivals every 5 years) and between 1600 and 1800 for visibility (about 2 aircraft arrivals per year). Although the morning periods also had aircraft affected by unprimed observations below the landing minima, the afternoon period where aircraft encountered unprimed visibility conditions between the landing and alternate minima had minimal aircraft affected by unprimed observations below the landing minima.

Figure 87: Visibility landing and alternate minima criteria by time of day. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.

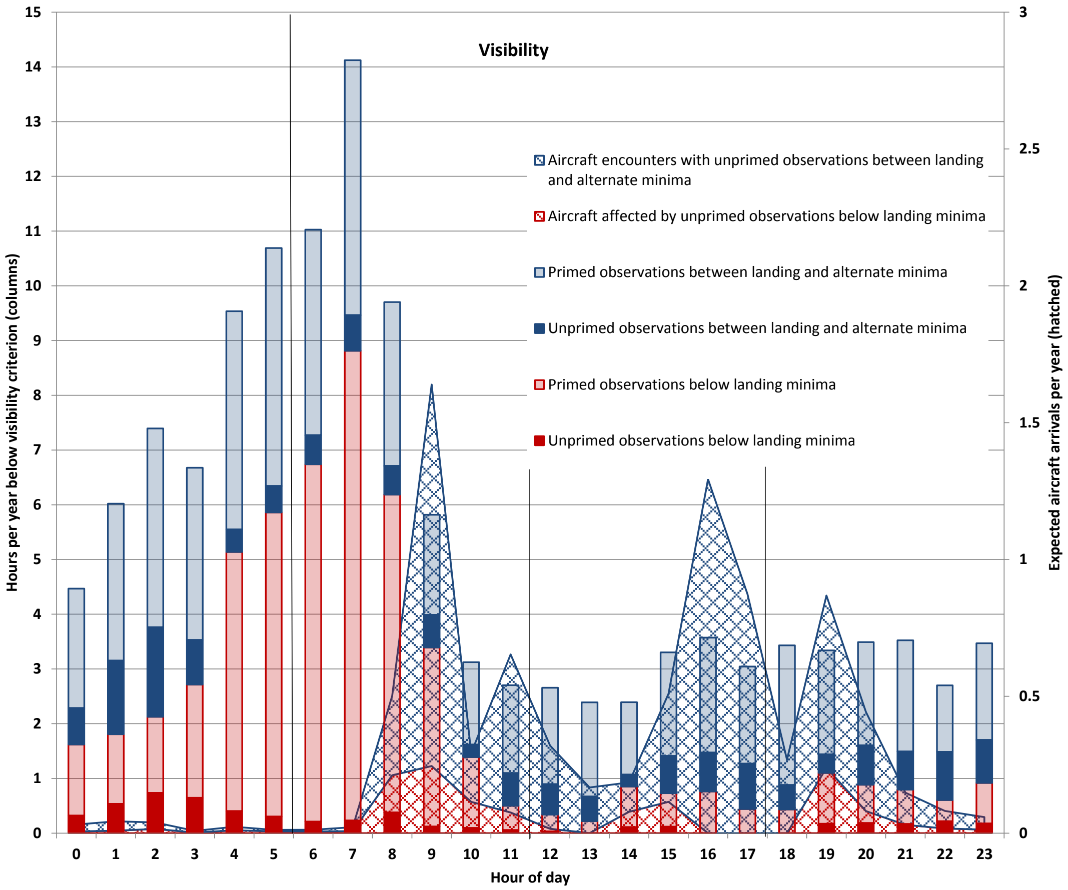


Figure 88: Ceiling landing and alternate minima criteria by time of day. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.

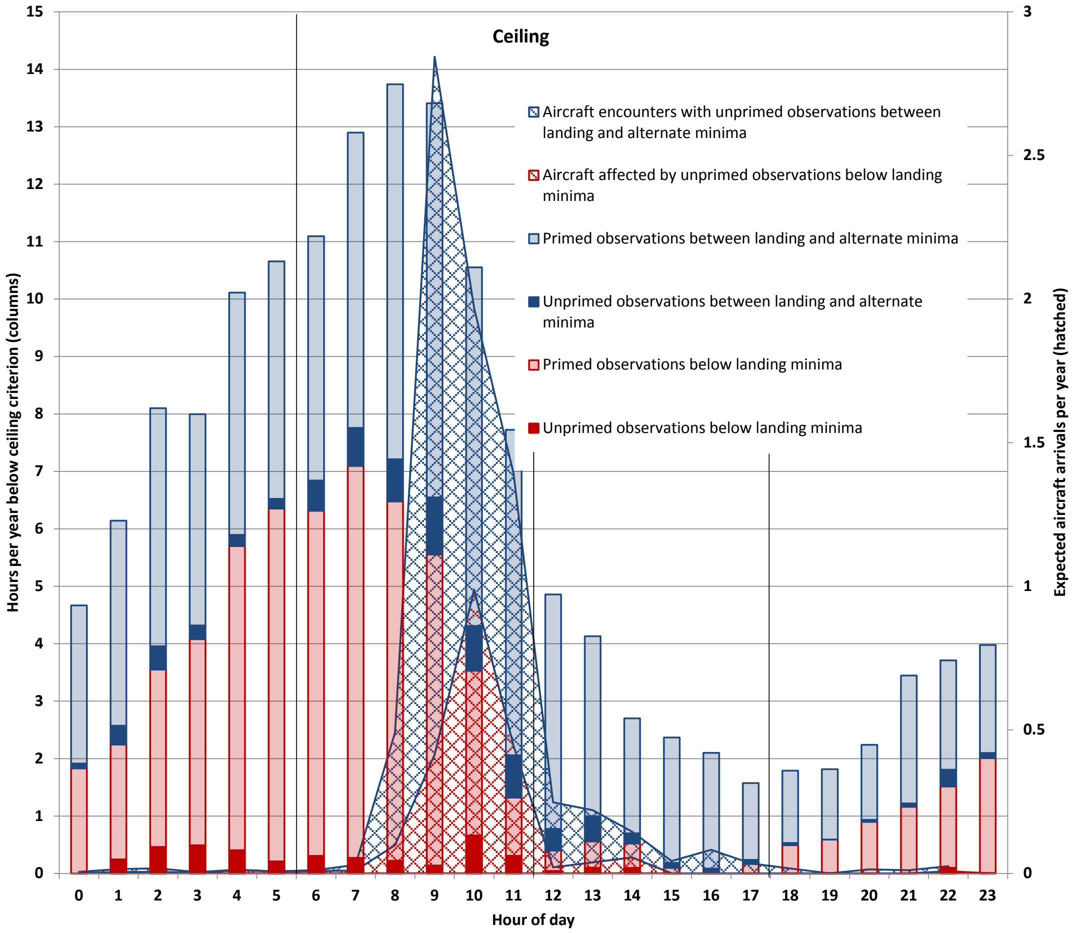


Figure 89: Tailwind minima criteria by time of day. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.

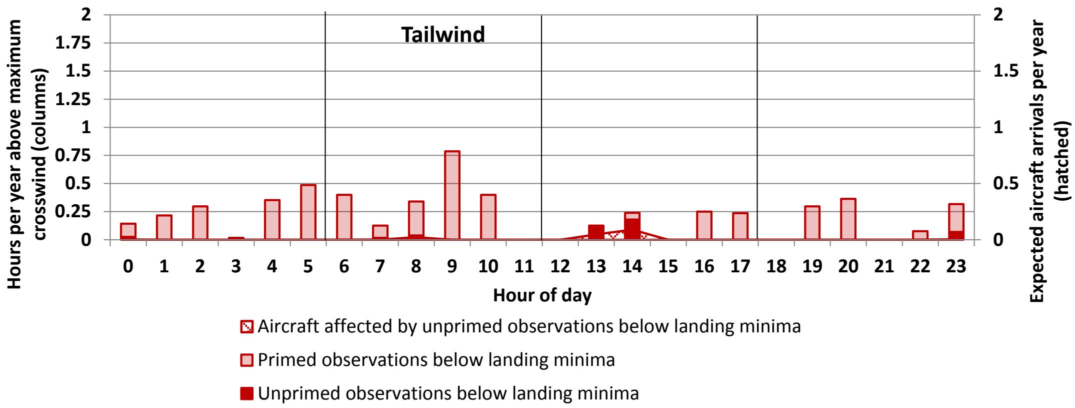


Figure 90: Crosswind minima criteria by time of day. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.

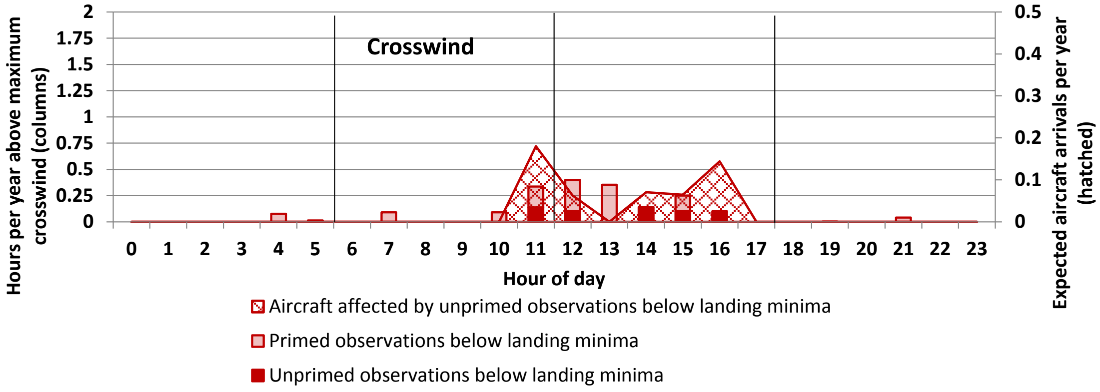
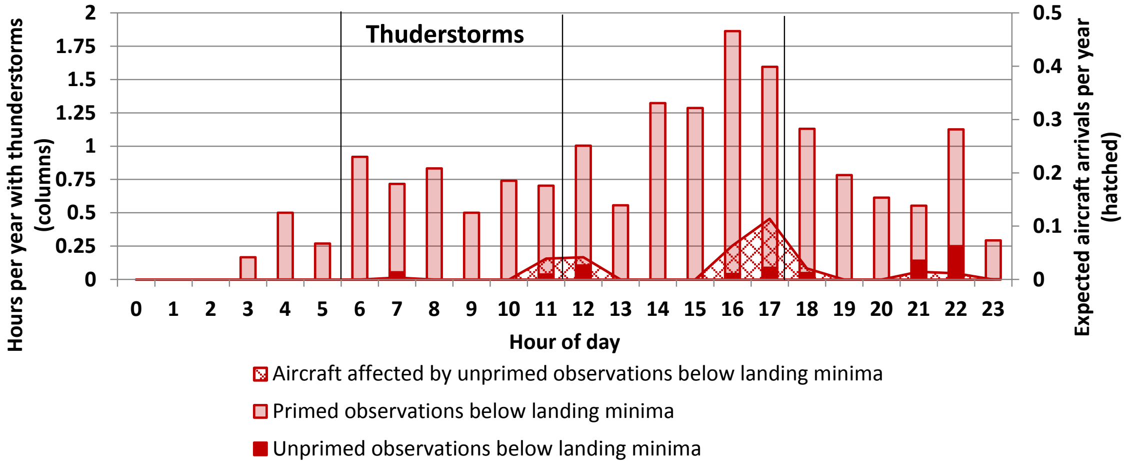


Figure 91: Thunderstorm minima criteria by time of day. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.



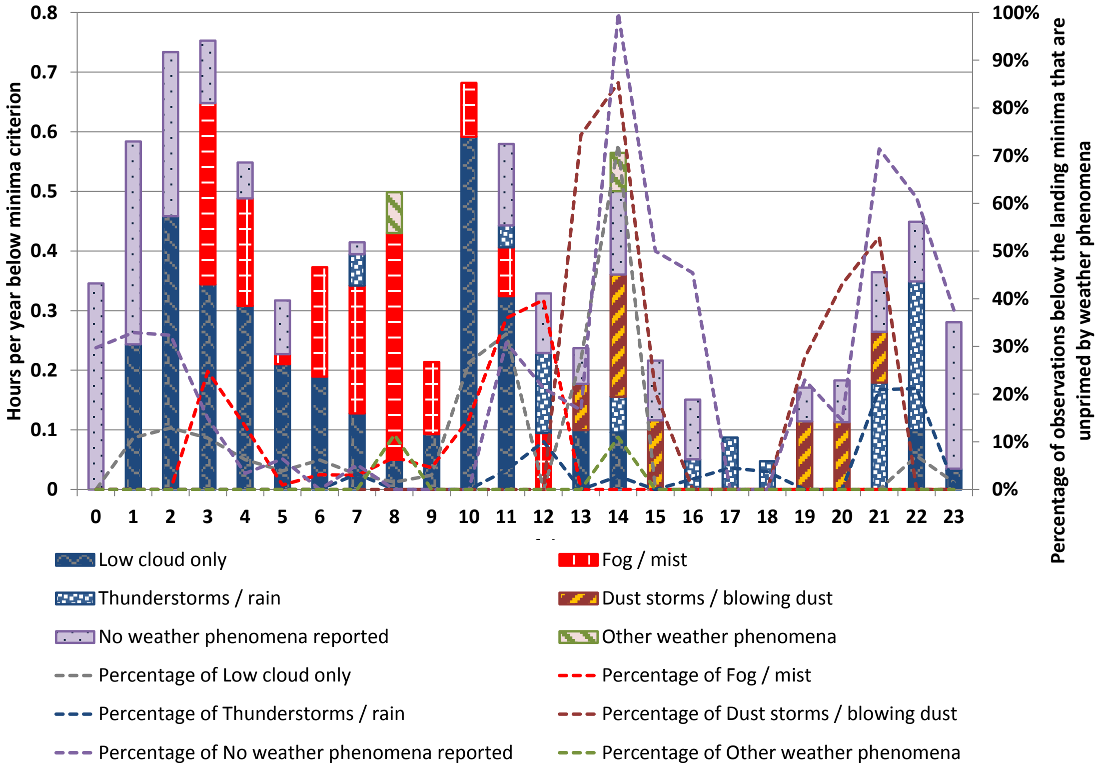
Unprimed weather phenomena

The weather phenomena contributing to the above unprimed minima criterion by time of day are shown in Figure 92. Between 1900 and 0800, all unprimed observations where no weather phenomena were reported (excluding low cloud) was during visibility below the landing minimum.

Unprimed visibility, often combined with fog and mist made up most of the known phenomena between 0300 and 1000 in the morning. The 10 to 1100 peak was driven mostly by unprimed low cloud (ceiling), possibly as a result of cloud lifting following a period of radiation or advection fog. This had the second highest percentage of observations below the landing minima that were unprimed in the morning, behind 1100 to 1200.

Blowing dust and dust storms were relatively more difficult to predict between 1400 and 1500 and 2000 to 2100, however, these were uncommon.

Figure 92: Weather phenomena reported during unprimed observations below landing minima by hour of the day.



Month of year

Minima criteria

The peak in observations below the landing minima in the colder months, in particular June and July, can be seen in Figure 93 and Figure 94 are mostly due to low visibility and ceiling. This also applies to unprimed observations below the landing minima. Additionally, unprimed observations were elevated in the month of January for visibility, and to a lesser extent, ceiling. However, when it comes to the aircraft affected by the unprimed observations below the landing minima, the ceiling criteria (due to low cloud) in July was the most prominent, with 1 aircraft on average expected to arrive each year during these times. This is a result of the time of day unprimed ceiling observations occurred (as discussed above).

Figure 93: Visibility landing and alternate minima criteria by month of year. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.

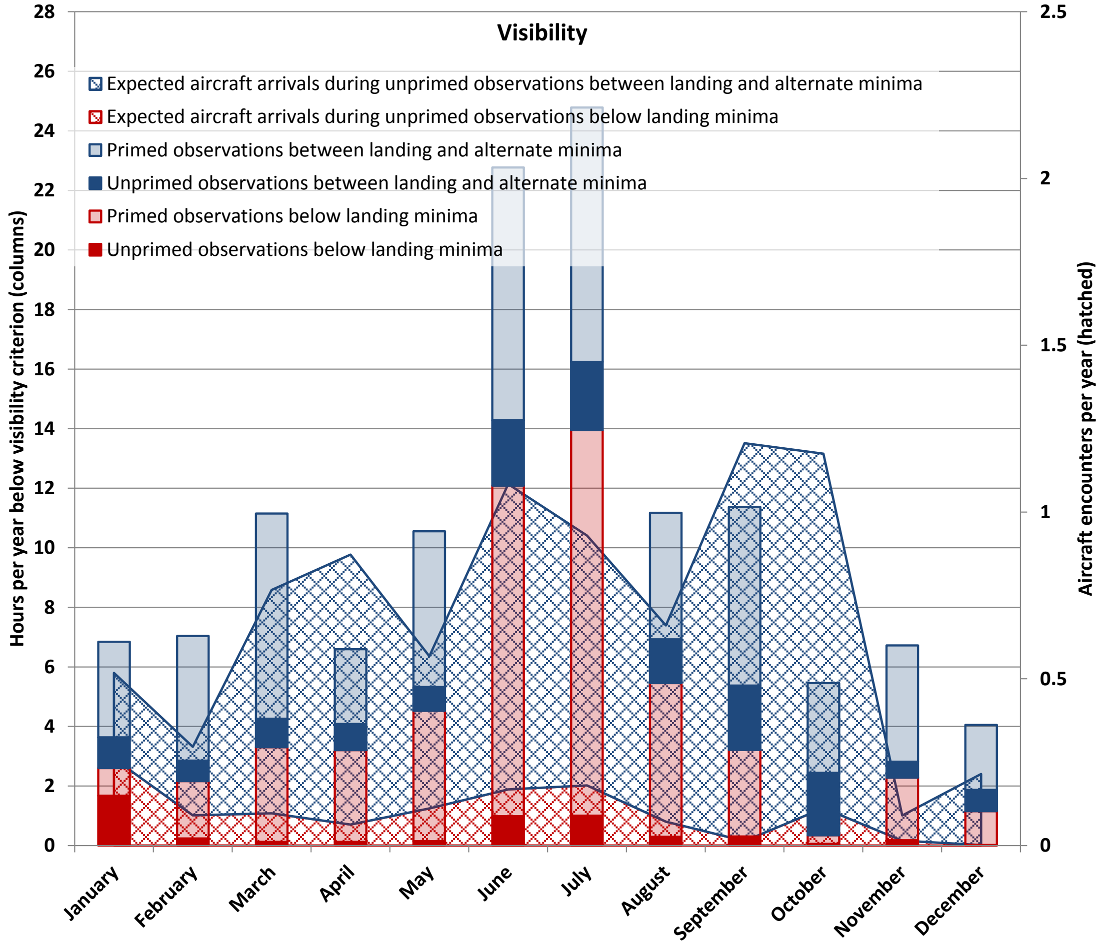


Figure 94: Ceiling landing and alternate minima criteria by month of year. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima (red) and between the alternate and landing minima (blue). Hatched area shows expected aircraft arrivals during unprimed conditions.

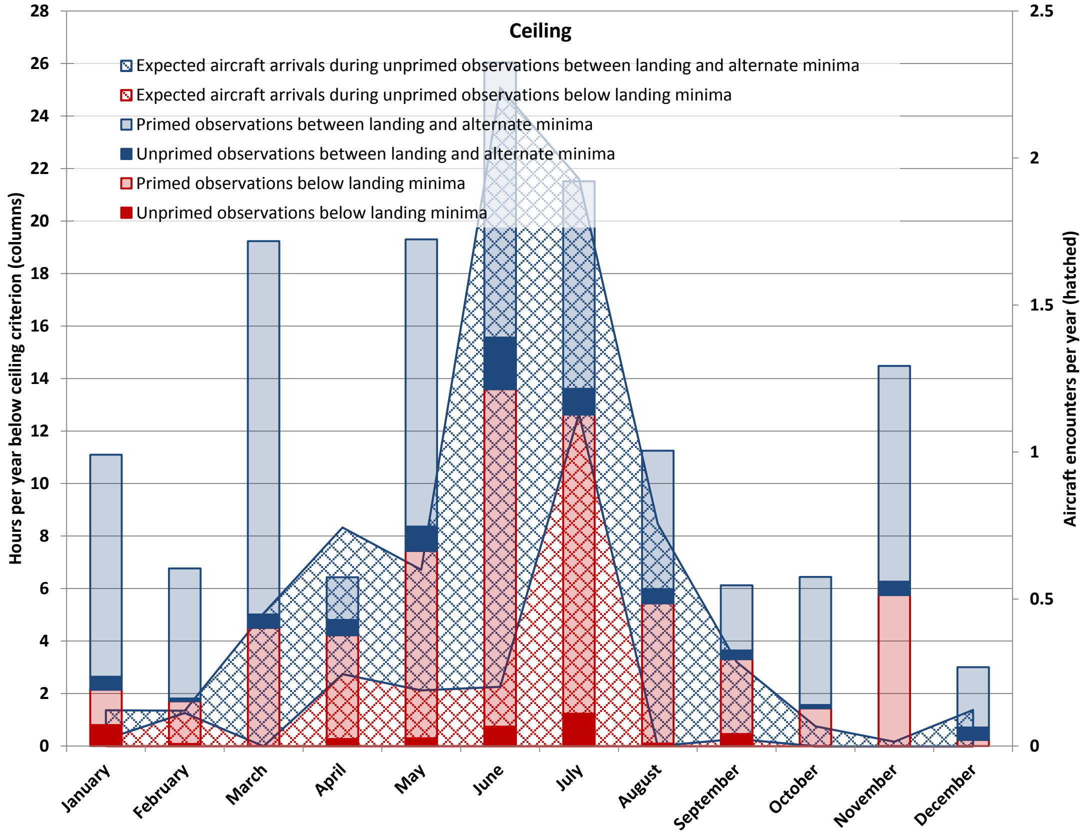


Figure 95: Tailwind landing minima criteria by month of year. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima. Hatched area shows expected aircraft arrivals during unprimed conditions.

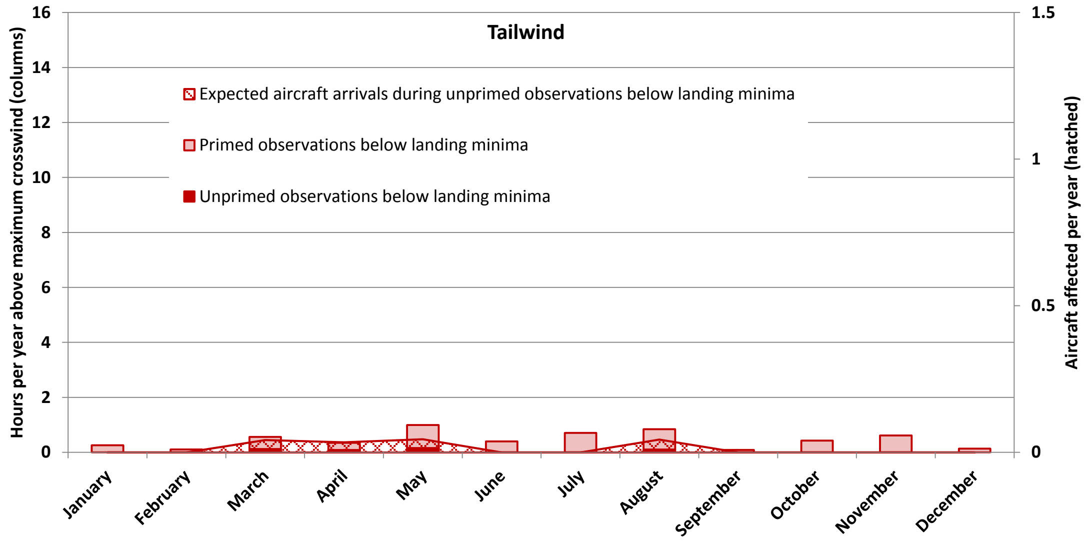


Figure 96: Crosswind landing minima criteria by month of year. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima. Hatched area shows expected aircraft arrivals during unprimed conditions.

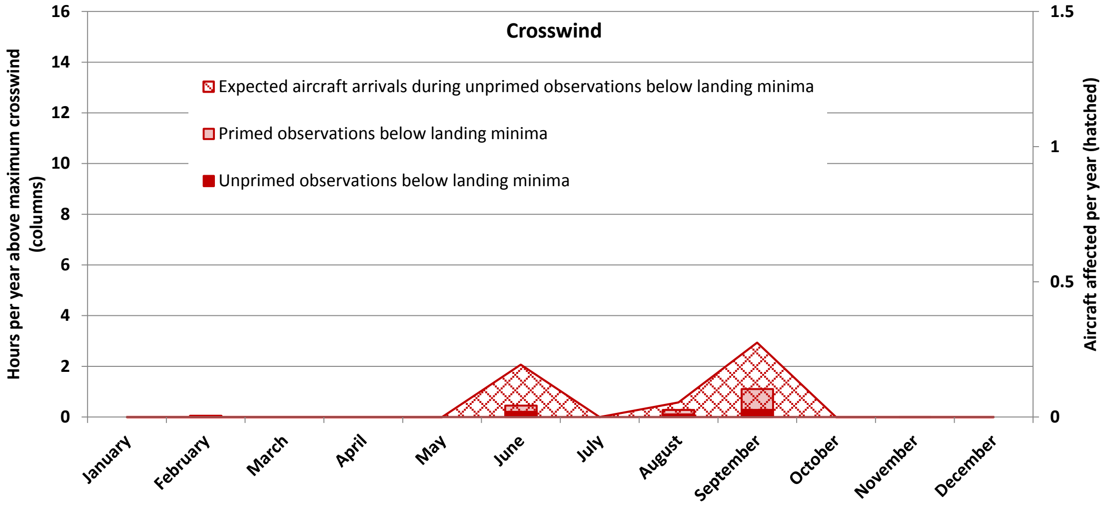
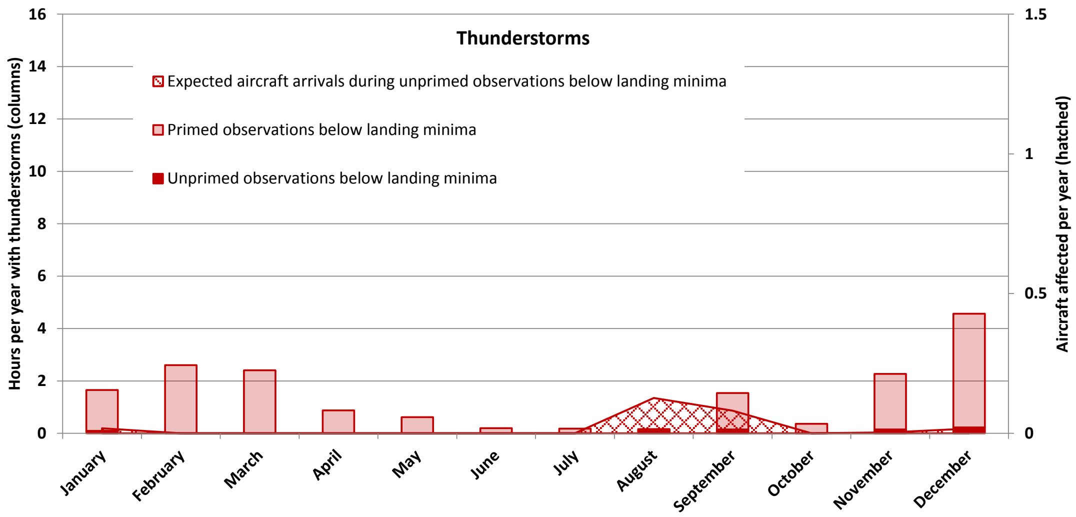


Figure 97: Thunderstorm landing minima criteria by month of year. Hours per year for unprimed (solid) and primed (transparent) observation below landing minima. Hatched area shows expected aircraft arrivals during unprimed conditions.



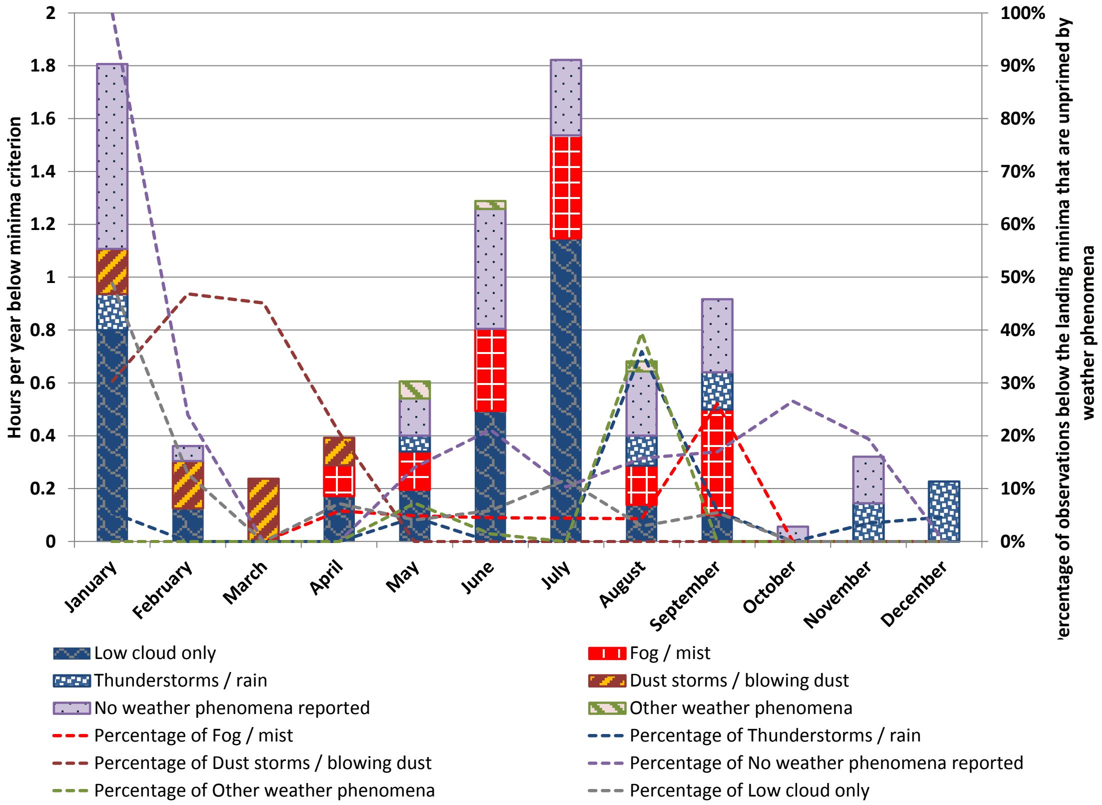
Unprimed weather phenomena

The weather phenomena contributing to the above unprimed minima criterion by month of the year are shown in Figure 98. Observations below the visibility minima where no phenomena were reported were the highest in January, making up 42 hours per year.

There were higher percentages of unprimed low cloud in January. The highest percentage of unprimed thunderstorms was in August at 36 per cent of all reported thunderstorms in that month.

Reduced visibility due the effects of dust were relatively more difficult to predict in February and March, compared with January and April, although this was relatively uncommon. All episodes in January and February were due blowing dust rather than dust storms.

Figure 98: Weather phenomena reported during unprimed observations below landing minima by month of the year.



Retrieval time

Unprimed minima criteria

Figure 99 shown the hours each year of unprimed observations for each minima criteria for up to 6 hours before arrival. Figure 100 shows the percent of all observations below the landing minima that were unprimed for each minima criterion.

Increasing the retrieval time prior to arrival has the greatest effect on the reliability of forecasts relating to visibility below the landing minimum, followed by ceiling below the landing minimum. The prediction of low visibility and ceiling have a similar percentage of observations below the landing minima that are unprimed.

The percentage of thunderstorms that were unprimed increased less than half as much as visibility at 6 hours prior to arrival. Cross-wind forecast reliability was not affected by the retrieval time. Scenarios where tailwind was calculated (in lieu of conditions below visibility and / or ceiling minima on a reciprocal runway) had a reliability between thunderstorms and low ceiling for retrieval times after two hours prior to arrival.

Figure 99: Hours per year of unprimed observations below the landing minima (at the time of arrival) for each minima criterion by forecast retrieval times between zero and 6 hours prior to arrival

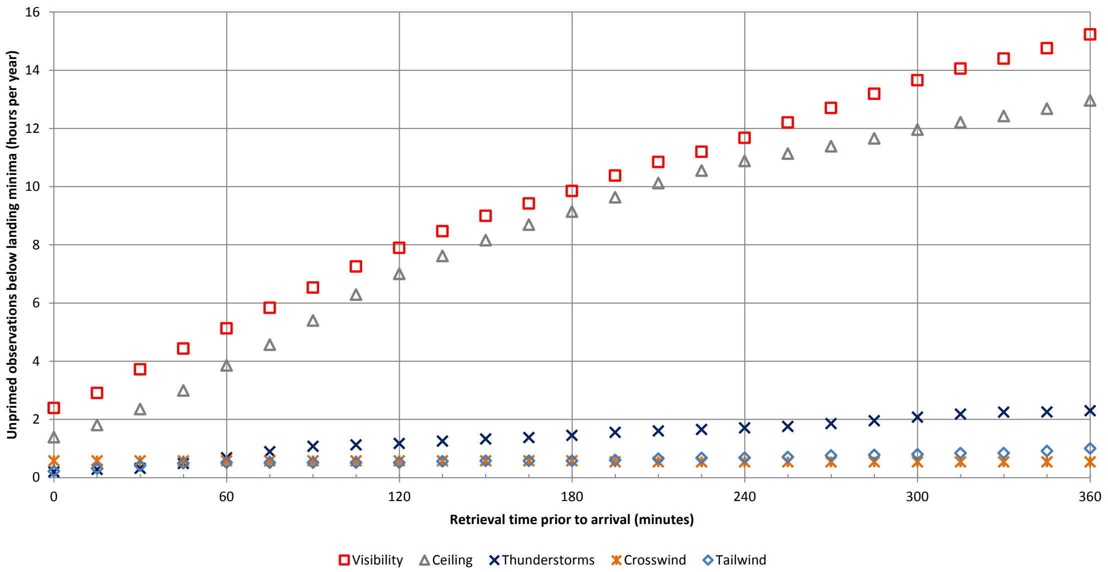
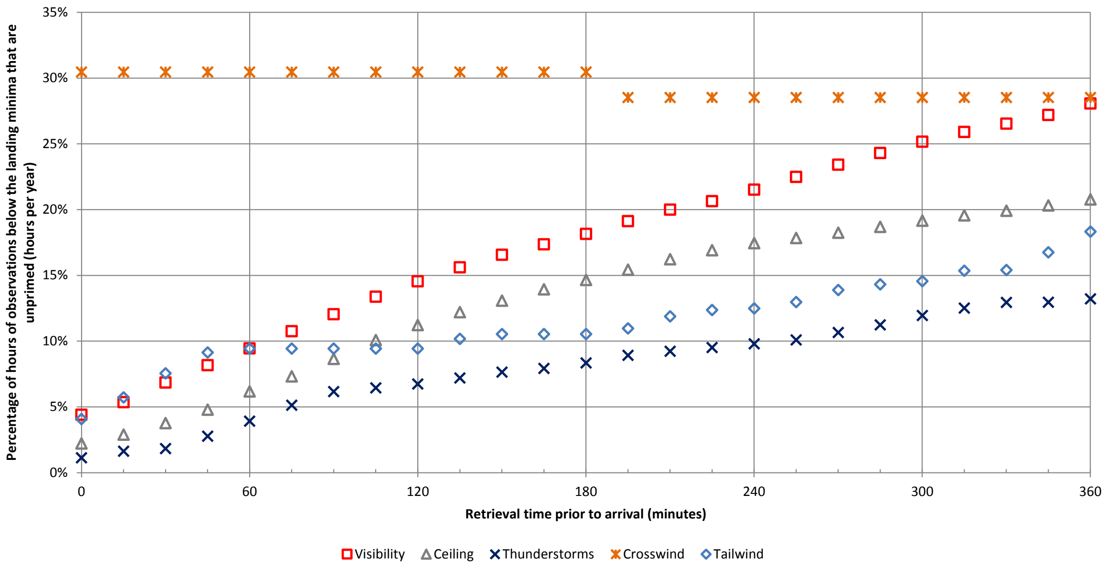


Figure 100: Percentage of observations below the landing minima (at the time of arrival) that were unprimed for each minima criterion by forecast retrieval times between zero and 6 hours prior to arrival



Unprimed weather phenomena

Figure 101 shown the hours each year of unprimed observations for each weather phenomena for up to 6 hours before arrival. Figure 102 shows the percent of all observations below the landing minima that were unprimed for each weather phenomena.

Fog and mist steadily increased in the hours of unprimed observation up to 6 hours prior to arrival. Similarly, no phenomena (up to 3.5 hours). Fog and mist reliability was very close to no unprimed observations at the time of the arrival.

The reliability of low cloud plateaued after 4 hours before arrival, from 1 in every 35 minutes down to 1 in every 5 minutes not predicted.

The sharp peak in lower reliability for forecasting dust/dust storms between 30 to 45 minutes prior to arrival can be seen in Figure 102. There are probably late indications of impending dust storms and blowing dust, with the most significant changes in the percentage between 0 and 45 minutes from about 1 in every 8 minutes of dust down to more than 1 in every 3 minutes for retrieval times greater than 45 minutes prior to arrival.

Figure 101: Hours per year of unprimed observations below the landing minima (at the time of arrival) for weather phenomena by forecast retrieval times between zero and 6 hours prior to arrival

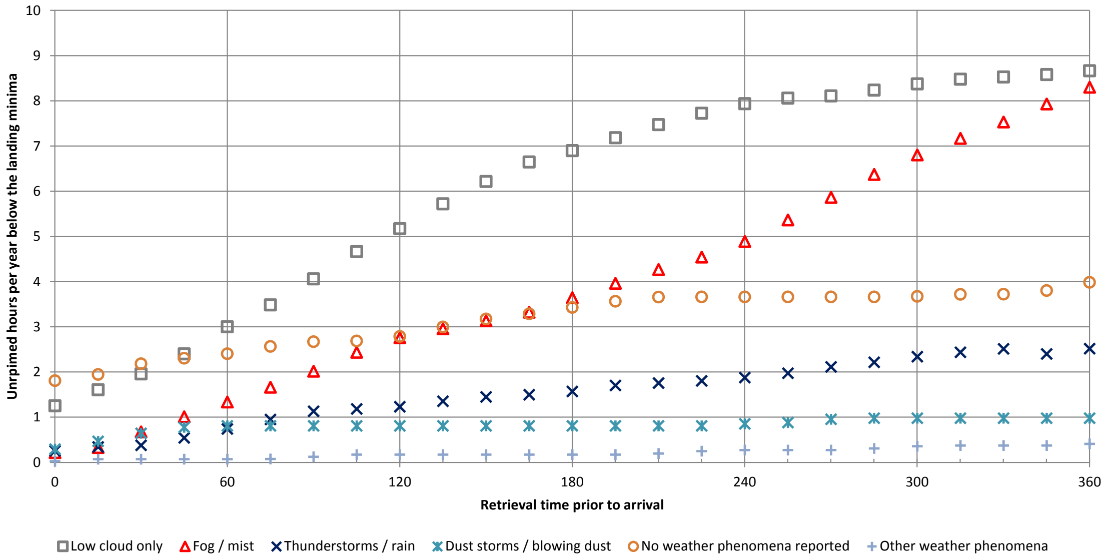
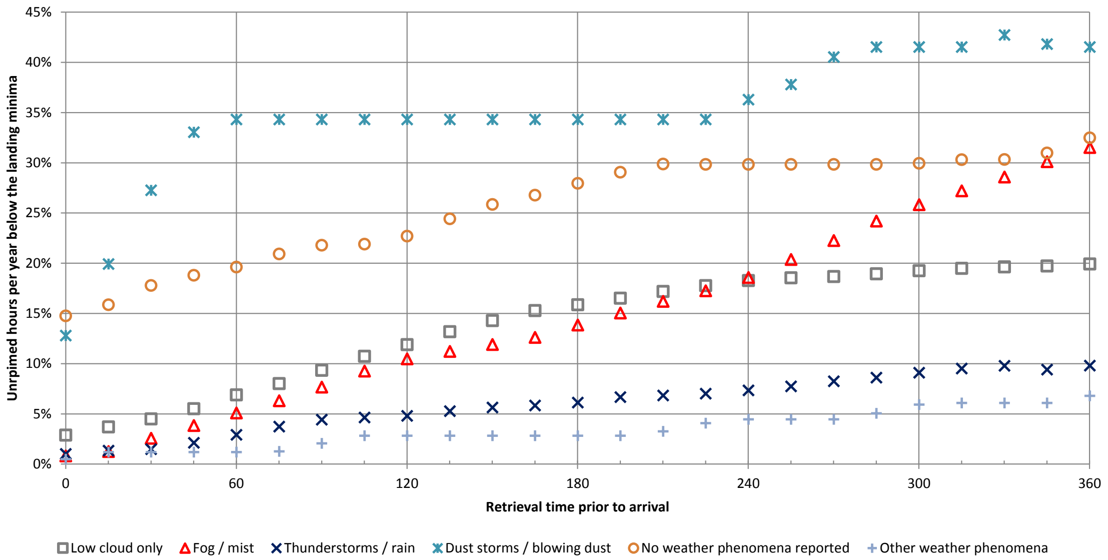


Figure 102: Percentage of observations below the landing minima (at the time of arrival) that were unprimed for reported weather phenomena by forecast retrieval times between zero and 6 hours prior to arrival



The effect of using thresholds below the alternate minima

This section is written to provide an indication of the increased relative likelihood of retrieving an unprimed forecast below the landing minima if using less stringent thresholds to those published in instrument approach procedures.

To evaluate these potential scenarios, an analysis of forecast conditions below the alternate minima was conducted.[69] This involved dividing the discrete variables visibility and ceiling, into additional categories from that shown in Figure 6. In the same way that reported observations were divided into three states, forecasts were divided into conditions above alternate, between the alternate and landing minima, and below the landing minima. Forecast landing minima criteria were chosen based on the runway approach 'expected' from the forecast.

Due to only two states existing for forecast thunderstorms or crosswind, these landing minima remained as represented in Figure 6.

Figure 103 shows the percentage of time below the landing minima within each forecast state described above, presented for forecast retrieval times 0 to 6 hours prior to arrival. These measurements are slightly different from those presented previously, in that they are measuring the proportion of forecasts in a particular state, rather than the proportion of all time.

This is intended to be flight operation-centric, indicating the odds of a forecast retrieved being unprimed if using forecast thresholds above, between or below the two minima.

For example, instead of asking the question, what are the odds today that I may receive a forecast that is unprimed, this analysis is asking, given the forecast prediction state, what are the chances that conditions will drop below the landing minima?

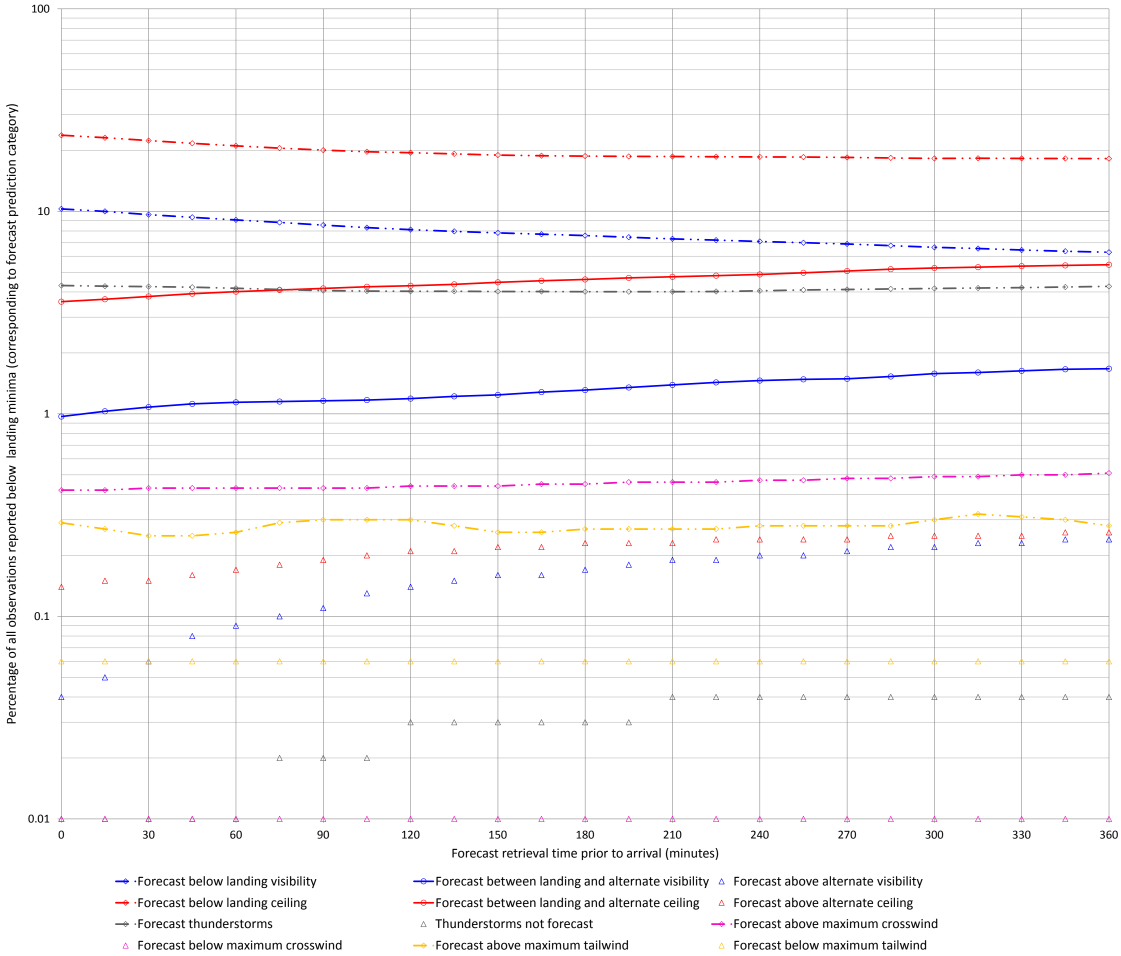
The vertical axis of Figure 103 represents the percentage of time that each forecast prediction and minima criteria were observed below the same landing minima state. For example, at the time of arrival (0 minutes on the horizontal axis), one in every 10 minutes of active TAFs predicting conditions below the landing visibility eventuate into reported visibility below the landing minima. This is shown by the blue broken line.

Note that there is overlap between each of the minima criterion as these were not excluded from the analysis due to the focus being on the relative likelihood within each minima criterion set.

The logarithmic vertical axis shows the relatively large difference between the forecast states within each minima criterion, with every increasing major division in Figure 103 representing a difference ten times (an order of magnitude) larger than the number below.

[69] At the time of writing, the effect of multiple forecasts being used to make operational decisions had not been evaluated, which may have an influence on the actual outcome. As such, results should be considered in terms of likelihood from retrieval of individual forecasts.

Figure 103: Percentage of observations reported below each landing minima within each forecast prediction category at Mildura Airport by retrieval time prior to arrival from 2009 to 2013



Forecast minima thresholds compared with retrieval time prior to arrival

Forecast ceiling thresholds

Conditions were reported below the landing ceiling about 3.6 per cent of the time at the time of arrival where active TAFs predicted a ceiling *between* the landing and alternate minima (shown as a red solid line in Figure 103). This number increased to 5.5 per cent of the time for TAFs retrieved 6 hours prior to arrival. TAFs predicting conditions above the alternate ceiling were below the landing ceiling 0.14 per cent of the time at the time of arrival increasing to 0.26 per cent of the time for TAFs retrieved with this condition 6 hours prior to arrival.

It should be noted that this does not take into account the possible effect of predictions of other minima criterion which would have an effect on the actual outcome, in particular the interaction between forecast ceiling and visibility.

For *any* retrieval time prior to arrival from 0 to 6 hours, if the landing ceiling was used for decision making instead of the alternate ceiling at Mildura, this equates to being at least 20 times more likely (with a maximum of more than 25 times more likely at the time of arrival) to retrieve a forecast resulting in arrival during reported conditions below the landing ceiling than when relying on the alternate minima threshold.

For example, one in every 26 minutes of available TAFs forecasting a ceiling between minima retrieved 30 minutes prior would result in arrival during reported observations below the landing ceiling. This is compared with reliance on the forecast alternate ceiling as a threshold 6 hours prior to arrival, at just over 1 in every 400 minutes.

At the time of arrival (0 minutes), just over one in every 4 minutes of available TAFs predicting conditions below the landing ceiling had reported observed conditions also below the landing ceiling. This decayed to just over 1 in every 5 minutes after 3 hours.

Forecast visibility thresholds

Forecast visibility *above* the alternate minima (Figure 103 blue triangles) compared with forecast visibility *between* the landing and alternate minima (Figure 103 blue solid line), were closer together with respect to the percentage of active forecast time observed below the landing minima, in contrast to the forecast ceiling of the same states.

However, there was still more than an order of magnitude (average of 16 times greater) between these for forecast retrievals up to 90 minutes prior to arrival, with the relative difference between the states decreasing gradually to 7 times more likely 6 hours prior to arrival.

The percentage of time observed below the landing minima for active forecast visibility *between* the landing and alternate minima (Figure 103 blue solid line) decayed from 0.97 per cent of the time at the time of arrival to 1.67 per cent of the time for TAF retrievals 6 hours prior to arrival. This is equivalent to 1 minute in every hour forecast *between* the landing and visibility minima being subsequently reported *below* the landing visibility at the time of arrival.

Due to visibility forecasting above the alternate minima becoming relatively more reliable close to the time of arrival, the relative odds are considerably more favourable when compared to forecast thresholds *between* minima. For example, for TAF retrievals 30 minutes prior to arrival, if visibility was forecast *between* minima, one in every 93 minutes would be observed below the landing visibility on arrival, compared to more than one in every 1500 minutes when relying on alternate visibility criterion.

One in every ten minutes of available TAFs predicting conditions *below* the landing visibility (Figure 103 dashed blue line) were actually reported below the landing visibility at the time of arrival. This decayed to one in every 16 minutes after 6 hours.

In comparison to forecasting of low cloud (ceiling), it appears that conditions of low visibility are predicted with lower precision at Mildura. This is based on the relatively lower proportion of visibility observations *below* the landing minima following forecasts *below* and *between* the respective minima (a higher proportion of false alarms).

However, there was a relatively higher proportion of ceiling forecasted *above* the alternate minima being reported *below* the landing minima on arrival (a higher proportion of unprimed observations). Note that this is different to Figure 100 which shows the resultant unprimed observations from the combined effect of all minima criteria, which is isolated in this case – this explains the larger proportion of unprimed visibility in that case.

Forecast thunderstorms, crosswind and tailwind

Thunderstorms, forecast conditions above the maximum crosswind and tailwind were included in Figure 103 to show the relative effect of these. Due to these being binary elements, only two states are shown.

As already shown in Figure 85, crosswind appears to have very small effect overall, and there was insufficient data to identify any systemic trends. However, note that on average one in every 220 minutes of forecast crosswind above the maximum aircraft limits was actually observed at the time of arrival.

Forecast tailwind above 10 knots (associated with visibility or ceiling below landing minima on runways with less precise approaches) occurred about 1 in every 6 hours when forecast. This was the least common forecast minima condition.

Thunderstorms were forecast and observed more frequently, with between one in every 23 to 25 minutes of forecast thunderstorms being reported at the time of arrival over the 6 hour retrieval time period. This was relatively less frequent than forecast visibility and ceiling at Mildura.

Unprimed observations for thunderstorms were also relatively less common than visibility and ceiling, with less than one in every 10,000 minutes of available TAFs not reflecting reported thunderstorms at the time of arrival. This increased to one in every 2,500 minutes for retrievals 6 hours prior to arrival.

In summary, when compared to forecast visibility and ceiling, thunderstorms are notably more reliable, albeit with a relatively higher proportion of false alarms.

Holistic operational effects of using different forecast minima thresholds

Figure 104 shows the overall effect of different minima thresholds (as labelled in the horizontal axis) if they were used for operational decision making instead of the alternate minima for the number of probable aircraft affected per year, and the forecast availability compared to all time between 2009 and 2013.

The horizontal axis values were calculated using a scaling process to standardise all values for different approaches and minima criteria into a single 'worst-case' value for each forecast segment. This allowed the calculation of the number and duration of observations reported below the landing minima in each 'worst-case' landing minima group, and also the calculation of probable aircraft affected. This involved setting the landing minima to a value of '1' and the alternate minima to a value of '2' and scaling the data to fit within this constraint.

This value was calculated according to the following process as outlined above in the Adelaide analysis (see page 96).

Data to the left of the line marked 'Alternate minima' in Figure 104 shows values for forecasts predicting conditions above the alternate minima, which were subsequently reported below the landing minima (unprimed).

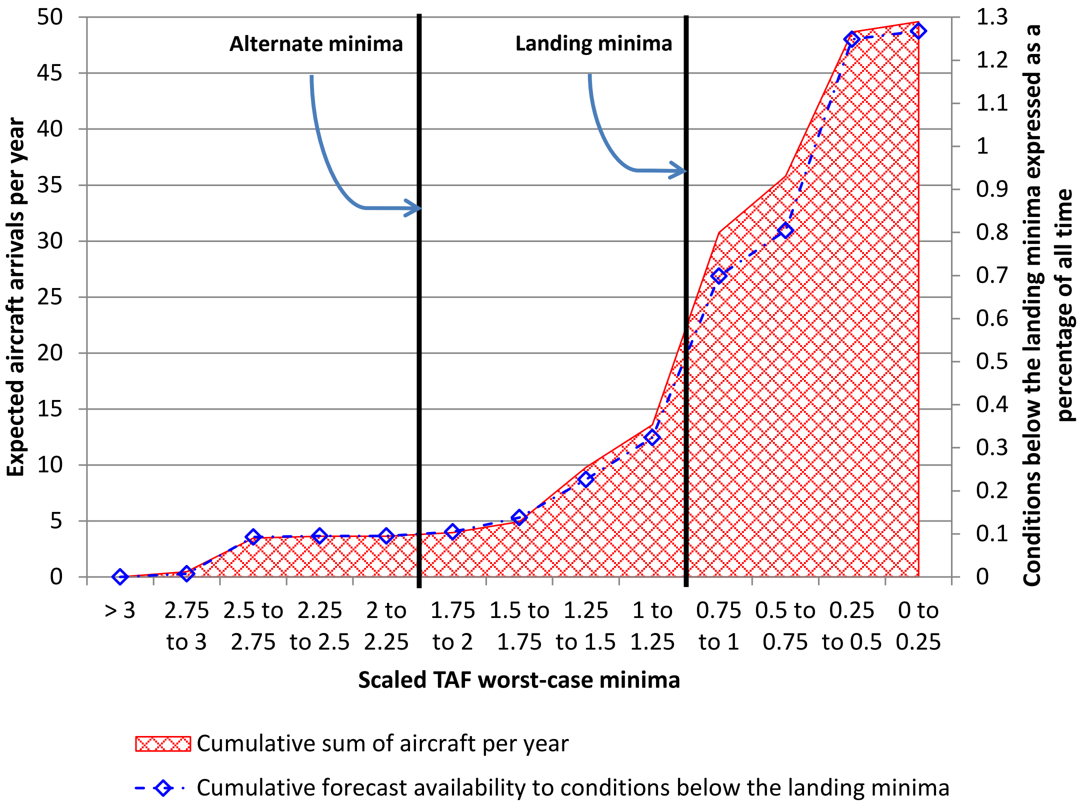
This shows cumulative percentage by the 'worst-case' TAF minima value (accumulated from left to right on the horizontal axis) of total time that forecasts were available, with reported observations below the landing minima on arrival (represented by the blue dashed line, and shown on the right hand side vertical axis).

Figure 104 shows the transition from forecast conditions above the alternate minima (on the left), between the alternate and landing minima (in the middle), to a forecast below the landing minima.

The data point labelled '2 to 2.25' located immediately left of the 'Alternate minima' line of Figure 104 represents the cumulative sum of all available forecasts predicting conditions above the alternate minima where observations are reported below the landing minima upon arrival. This can be seen in Figure 63, which shows the percentage of these conditions as 0.1 per cent (as shown by the blue dashed line). This also shows 3.6 expected aircraft arrivals per year (shown in the red shaded area and indicated in Figure 64), and measured from the left side vertical axis of Figure 104.

On the right side of Figure 104, the data point labelled '0 to 0.25' indicates the cumulative total of all observations below the landing minima. This can be seen by the cumulative total of forecast availability adding to 1.3 per cent, which is also shown in Figure 63 as the sum of the observations below the landing minima in the orange and light blue shading. Figure 104 also shows a maximum of almost 50 expected aircraft arrivals during conditions below the landing minima.

Figure 104: Probable aircraft affected per year and overall percentage of forecast availability to observations below the landing minima by scaled TAF worst-case minima value for forecast retrievals zero to 2 hours prior to arrival 2009 to 2013



Operational effect of reliance on forecasting between landing and alternate minima

The middle segment of Figure 104 shows the cumulative calculation of probable aircraft affected and the cumulative percentage of all time for arrivals during observations below the landing minima by TAF worst-case minima. This shows a marked increase in both probable aircraft affected and availability from the alternate minima to the landing minima. This shows the effect of using a selected forecast value for operational decision making.

For example, if the alternate minima was decreased to between 1.25 and 1.5 (25 to 50 percent of the way between the landing and alternate minima), there would be an increase from 3.6 to 9.8 unprimed aircraft arrivals per year.

Furthermore, if the landing minima was used instead of the alternate minima, this would result in about 13.6 unprimed aircraft arrivals per year (3.7 times the number when using the alternate), making up 26 per cent of all observations below the landing minima.

This shows that at typical times of day at Mildura where a flight crew may be approaching a point of no alternate between 0 and 2 hours prior to arrival, the chances of arriving during conditions below the landing minima are considerably increased when relying on the forecast landing minima compared with the alternate minima.

Alternate minima threshold assessment

The effect of varying the alternate minima threshold can be seen in Figure 104 looking to the number of aircraft affected and forecast availability on each side of the alternate minima line.

This shows that shifting the alternate minima 25 per cent of the way toward the landing minima would result in a slight increase in the number of aircraft affected and unprimed availability. Conversely, shift the alternate minima 25 per cent away from the landing minima would result in very slight decreases in unprimed observations and aircraft affected.

This suggests that overall, alternate minima criteria for visibility and ceiling are positioned at relatively stable values, with only slight benefit or loss from small perturbations. In other words, even if the alternate minima was altered slightly, there would be no significant change to the system.

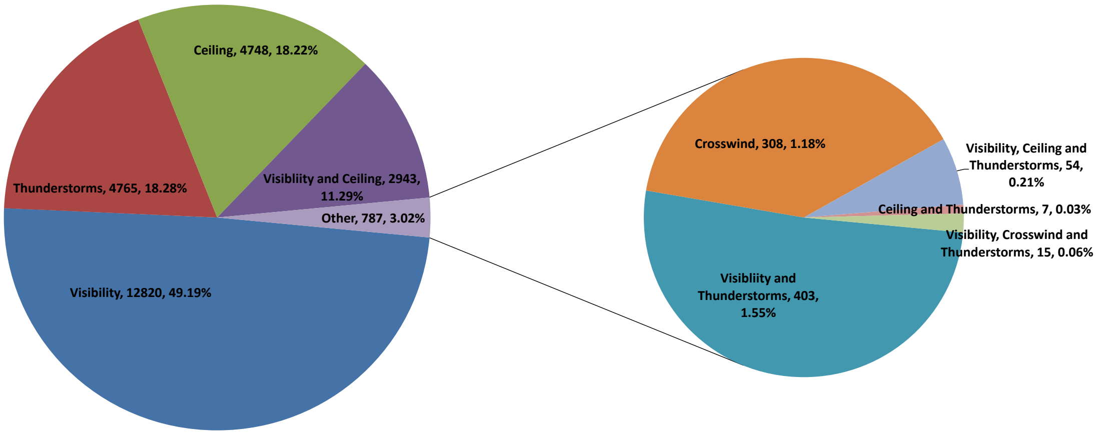
Appendices

Appendix A – Selected TTF, TAF and METAR/SPECI results

Table 8: Overview of landing minima parameters for periods below the landing minima at Adelaide Airport 2009 to 2013

Episode landing minima	Number of episodes	Landing minima observed at the same time	Duration (minutes)	Expected aircraft arrivals
Thunderstorms	42	Thunderstorms	2,345	242.4
Ceiling and visibility	7	Ceiling and visibility	1,006	89.9
		Ceiling	271	31.6
		Visibility	46	1
Ceiling, visibility and tailwind	2	Ceiling and visibility	259	23
		Ceiling and tailwind	124	20.9
		Visibility	120	6
		Tailwind	99	14.3
		Ceiling	45	5.4
Ceiling	4	Ceiling	425	30.1
Visibility	6	Visibility	338	6.6
Visibility and thunderstorms	2	Thunderstorms	171	17.2
		Visibility and thunderstorms	20	2.5
Thunderstorms and tailwind	1	Thunderstorms	167	23.3
		Tailwind	13	1.4
Ceiling and tailwind	1	Ceiling	88	2.9
		Tailwind	67	9.4
Tailwind	7	Tailwind	129	15.3
Crosswind	8	Crosswind	123	17.1
Thunderstorms and crosswind	3	Thunderstorms	51	6.3
		Crosswind	25	3.2
		Thunderstorms and crosswind	2	0.4
Thunderstorms, crosswind and tailwind	2	Crosswind	24	2.1
		Thunderstorms and crosswind	17	0.3
		Thunderstorms	17	0.2
		Thunderstorms and tailwind	10	0.2
		Tailwind	4	0.5
Visibility and tailwind	1	Visibility	15	3
		Tailwind	3	0.6
Total	**86**		**6,024**	**577.1**

Figure 105: Proportion of time (minutes) below the landing minima by conditions breached within METAR and SPECI reports



Appendix B – Releases of SPECIs following conditions below the landing minima

The current analysis uses reported observations to approximate actual conditions, this period begins at the time of the report release through to the release of the next report (up to a limit of 60 minutes between reports). The release frequency of these reports is discussed in *General release timing characteristics of METARs and SPECIs* below.

The focus of this study was on unsuitable conditions for an aircraft to land (below the landing minima). Therefore, it was considered important to understand if any artificial delay was applied at the cessation of conditions below the landing minima. If this was the case, an overestimate of the duration of conditions below the landing minima would be present in the analysis.

Expected observed time-based characteristics with a 10 minute artificial delay applied to any improvement SPECI

If the hypothesis that a 10 minute delay was applied to the release of SPECIs each time conditions improve through nominated thresholds, a number of characteristics would be expected in the data. Two of these are examined.

- There would be no improvement SPECIs released within 10 minutes of the previous SPECI
- A marked spike in the release of improvement SPECIs at 10 minutes after the previous SPECI

Observed time-based characteristics of SPECIs reporting conditions below the landing minima

To examine the effect if any of artificial delay in data, SPECIs were grouped into the following categories based on the weather report released immediately prior (thunderstorms and wind changes were not categorised, although were evaluated as a group).

- Deterioration SPECI (Visibility and ceiling) – any drop in visibility or cloud base from previous report.
- Improvement SPECI (Visibility and ceiling) – any increase in visibility or cloud base from previous report, and no deterioration.
- Temperature or pressure changes – change by 1 hectopascal or 1 degree Celsius.
- No change – none of the above conditions changed.

Figure 106 shows the cumulative percentage of reports by the time between weather report releases (either immediately prior to, or after the report of interest). This was restricted to reports released at intervals up to 20 minutes and conditions below the landing minima. The purpose of these graphs is to show a comparison of the release frequency of different types of reports in each category.

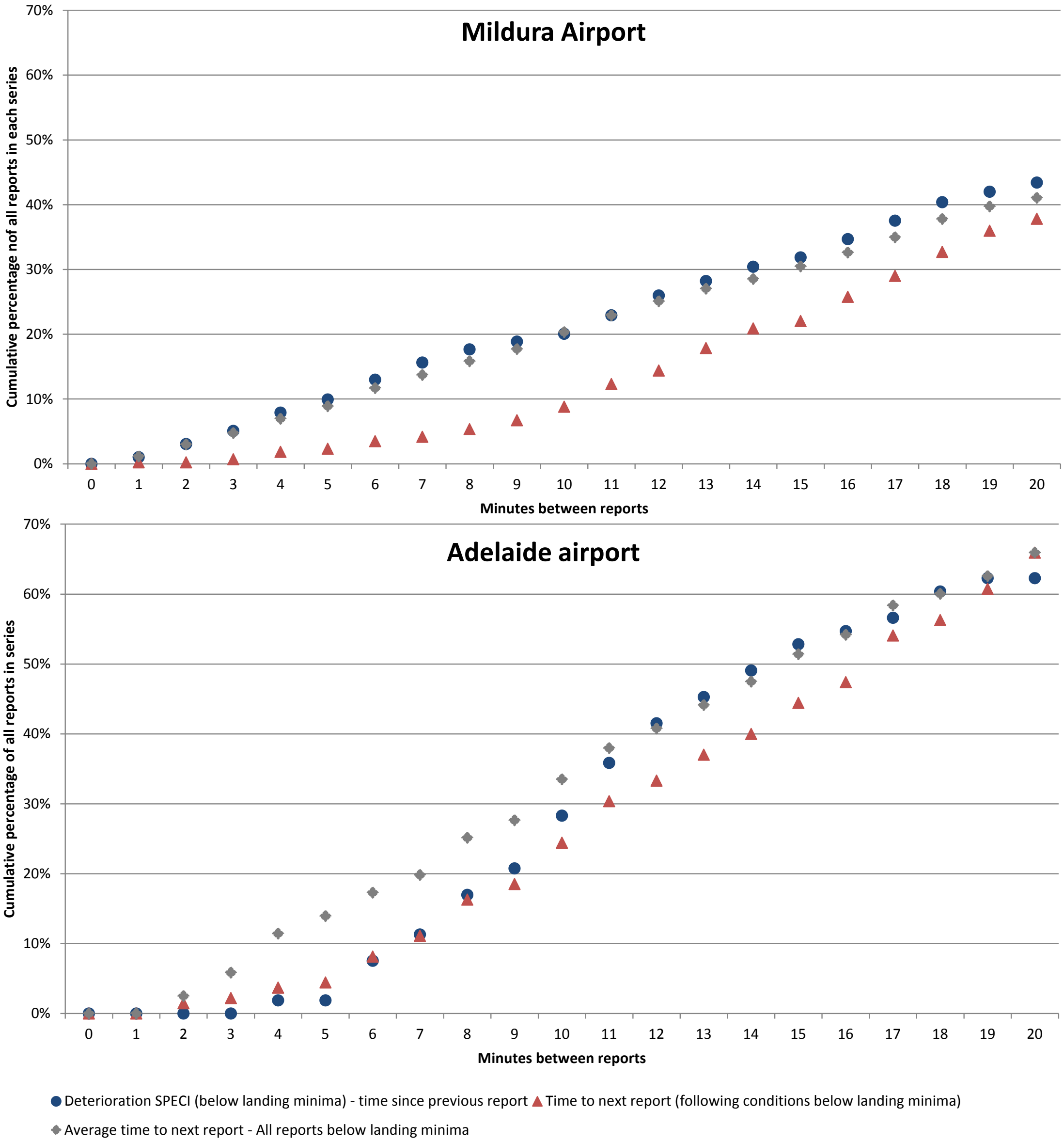
The cumulative percentage of the time between reports above the landing minima and reports below landing minima immediately prior are shown as red triangles in Figure 106. Of particular note for both Mildura and Adelaide Airports, these reports are released within 10 minutes of the report below the landing minima, indicating that the potential effects of any artificial time delay do not apply in all cases (if any).

For Mildura Airport, reports immediately following periods below the landing minima are released less frequently in the first 10 minutes when compared to SPECIs reporting deteriorated cloud or visibility (blue circles), and also the average release interval for all SPECIs below the landing minima (grey diamonds). This may indicate that there is some delay in release, when compared to other reports.

In contrast, Adelaide Airport, reports immediately following periods below the landing minima were similar for release intervals up to 10 minutes following when compared to SPECIs reporting deteriorated cloud or visibility. This data does not support there being any artificial delay in release of SPECIs following periods below the landing minima. Both of these were below the average SPECI release intervals for conditions below the landing minima.

From these observations, it is considered that the effect of any artificial time delay following periods below the landing minima is very small. For the purpose of using a SPECI to represent conditions from its release until the next report release to represent actual time periods below the landing minima, the effects of an artificial delay are assumed to be negligible at Adelaide and Mildura airports.

Figure 106: Minutes between reported observations during and following conditions below the landing minima by cumulative percentage of weather reports (METARs or SPECIs) in each category, 2009 to 2013 (first 20 minutes shown)



General release timing characteristics of METARs and SPECIs

The vast majority of standard meteorological reports (METARs) were released every 30 minutes at Adelaide (99%) and Mildura (98%) airports between 2009 and 2013. There was no significant variation in the frequency of release of METARs for conditions above the alternate minima. Almost all METARs and SPECIs at Adelaide and Mildura airports contained some information from an automatic weather station (AWS).

There were 21 METARs at Mildura and 7 METARs at Adelaide released when conditions were below the alternate minima.

Special meteorological reports (SPECIs) had notably more variation in the frequency of release times for all conditions.

There were slightly more SPECIs released overall for conditions above the alternate minima at Mildura, with 3,905 SPECIs reporting conditions above the alternate minima compared to 3,779 SPECIs reporting conditions below the alternate minima (including conditions below the landing minima). In contrast, considerably more SPECIs were released for Adelaide for conditions above the alternate minima (8,050 SPECIs above compared with 1,049 below).

More than half of all SPECIs reporting conditions between the landing and alternate minima were released within 20 minutes of the prior meteorological report for Adelaide and Mildura Airports. More than 74 per cent of SPECIs above the alternate minima were released less than 30 minutes since the previous report.

The distribution of SPECI release times less than 30 minutes since the previous report release was relatively constant from 1 to 29 minutes since prior release. This is shown by the steady increase of all cumulative percentages up to 29 minutes in Figure 107 and Figure 108. This is consistent with these SPECIs being reactionary to changing conditions, and therefore being out of phase with ordinary forecast release cycles. Almost all of these reports were released within 35 minutes of the previous report.

Figure 107 and Figure 108 also show the number of SPECI reports by the time since the previous report release, categorised by conditions above the alternate minima, between the alternate and landing minima, and below the landing minima.

Comparing Adelaide to Mildura Airport, there was relatively higher frequency of SPECIs reporting conditions below the landing minima within 30 minutes of the previous report (shown by the purple dotted line in Figure 107 and Figure 108). In contrast, a relatively higher proportion of SPECIs reporting conditions above the alternate minima were released for Mildura within 30 minutes of the previous report compared to Adelaide.

Figure 107: Distribution and cumulative percentage of SPECI type meteorological reports by time since previous release at Mildura Airport 2009 to 2013

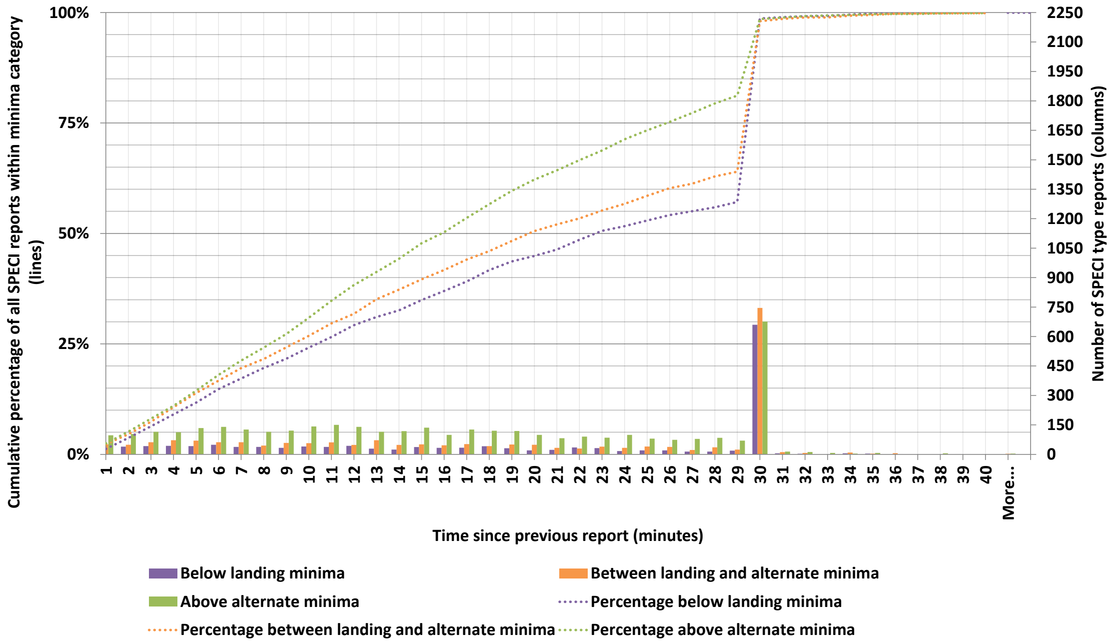
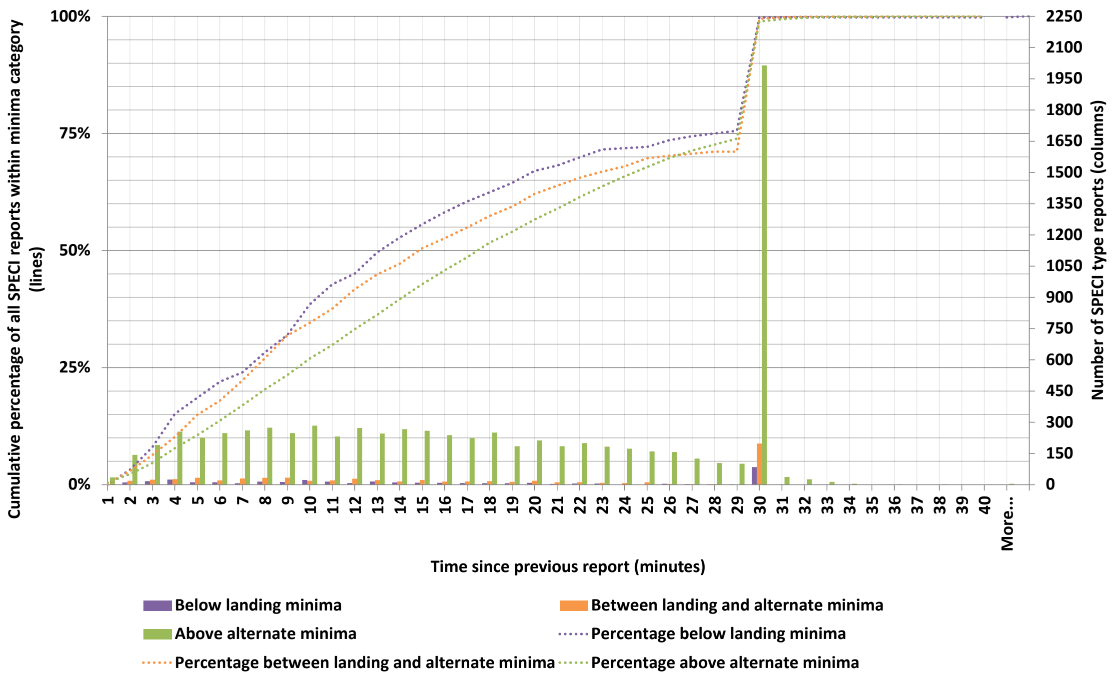


Figure 108: Distribution and cumulative percentage of SPECI type meteorological reports by time since previous release at Adelaide Airport 2009 to 2013



Appendix C – Data validation and assumptions supporting data

Table 9: Assumed visibility and ceiling in the absence of explicit values for elements in TAF, TTF, METAR and SPECI weather products

Order of preference	Value Category	Weather Element	Applicable weather products[70]	Nominal value	
				Visibility	Ceiling
1	Explicit	Visibility or cloud data	METAR, TAF, TTF	As reported[71]	Reported cloud layers
2	Weather condition flags	SKC	METAR, TAF, TTF	N/A	9999
		NSC	METAR, TAF, TTF	N/A	4999
		NCD	METAR	N/A	4999
		CAVOK[72]	METAR, TAF, TTF	9999	4999[73]
3	Explicit	Vertical visibility	METAR	As reported	As reported
4	Ceilo-meter and visibility sensor anomaly	CLD:SKY MAY BE OBSC	METAR	As reported or 999	3 degree slant visibility height[74]
5	Explicit	Remarks section data	METAR	As reported	As reported
6	Average	Average between reports	METAR	Average of surrounding reports	Average of surrounding reports

Table 10: Number of weather reports by type of visibility value used, 2009 to 2013

Visibility value	Number of METARs and SPECIs	
	Mildura	Adelaide
Explicitly reported in body text	14,581	51,895
Flags used: CAVOK (Set to 9999)	35,982	40,035
Sky Obscured: Set to 999	36	0
Visibility explicitly extracted from remarks section (VIS: XXXX)	40,603	251
No estimation found - exclude record from analysis (Set visibility to NULL)	1	2

70 Due to the first segment of a TTF being the METAR body text, METAR values are applied in these cases for the first period of the TTF, including where NOSIG is forecast.
71 This includes explicitly recording minimum visibility in a separate field.
72 Values based on CAVOK definition from AIP GEN 3.5 section 12.13 dated 29 May 2014.
73 Although the CAVOK definition requires that clouds are also above the lowest minimum sector altitude in a 25 nautical mile radius, the focus of these calculations is to align the values of forecasts and observations overhead the aerodrome in a consistent way.

Table 11: Number of weather reports by type of ceiling value used, 2009 to 2013

Ceiling value	Number of METARs and SPECIs	
	Mildura	Adelaide
Reported in body text octas >= 5	10,179	33,386
Octas sum > 0 but < 5 set ceiling to 4999	4,075	18,286
Flags used: SKC (set to 9999), NSC, NCD, CAVOK (set to 4999)	36,220	40,165
CLD: Clear Below XXX, (set to XXX)	28,613	155
Explicit cloud groups in remarks	12,033	189
Slant Visibility Height where CLD: SKY MAY BE OBSC reported	36	0
Average of observations immediately prior and after METAR within set time limits	47	2

Definitions and terms

The terminology used in this report is intended to match that used by the Bureau of Meteorology and Airservices Australia, which is in general conformance to International Civil Aviation Organization standards. For clarification on any specific meteorological or aeronautical terms, please refer to Bureau of Meteorology or Airservices Australia documentation.

Active forecast – A single component of a TAF or TTF used for operational decision making at a particular point in time. Note that there can only be one TAF and TTF forecast active at a given time.

Aerodrome forecast – see *TAF (aerodrome forecast).*

Aerodrome weather reports – Reports of observations of meteorological conditions at an aerodrome. There are two types of weather reports described below. The most current report (either a METAR or SPECI) is used to represent observations for this analysis until the release of the next report.

- ***Routine reports (METAR)*** – Aerodrome weather reports issued at fixed times (generally half hourly at Adelaide and Mildura).
- ***Special reports (*SPECI)** – Aerodrome weather reports issued whenever weather conditions fluctuate about or are below specified criteria.

Alternate minima – Specified weather conditions or facilities for a particular aerodrome such that, if the weather conditions or facilities are less than the alternate minima, the pilot in command must provide for a suitable alternate aerodrome.

Calculated holding time – The duration of time that an aircraft would be unable to land due to weather conditions after arriving at the destination following the retrieval of a forecast above the alternate minima when conditions were observed below landing minima at the time the aircraft arrived at the destination.

Ceiling – The height above the ground that more than half of the sky is covered by cloud when observed from the ground.

Crosswind – The component of wind blowing at right angles to the runway direction.

Expected aircraft arrivals – An estimate of the number of aircraft arrivals over specified time periods from an aircraft arrivals data model developed from historical aircraft arrivals patterns.

False alarm – Observation of weather conditions above the alternate minima preceded by a weather forecast (TAF or TTF) for conditions below the alternate minima.

Forecast – Any component of a TAF or TTF bounded by a documented period of time containing a statement of expected weather conditions within this duration. This includes any significant changes, temporary variations and probability of change for thunderstorms or fog. Note that there are often multiple forecasts within a TAF or TTF.

Forecast comparison state – One of nine logical comparisons of forecasts and observations. These are based on all combinations of forecasts and observations above the alternate minima, between the alternate and landing minima and below the landing minima.

Forecast retrieval time prior to arrival – The period of time before landing that a forecast is retrieved by pilots.
The forecasts used for analysis are those which were most current and available from flight information services at the nominated time prior to arrival, which contain predictions for the observation period. For a set forecast retrieval time, there is no overlap for forecast–observation comparisons. For example, if a forecast is available for retrieval by operational personnel for 30 minutes, between 1100 and 1130, and a forecast retrieval time set at 2 hours prior to arrival, the

evaluated period for this active forecast (assuming it contains predictions for this period) would be between 1300 and 1330.

Global navigation satellite system (GNSS) – Satellite-based radio navigation system that uses signals from a constellation of orbiting satellites to determine precise location and time. This is often known colloquially as the Global Positioning System (GPS), which refers to only one of these orbiting constellations of satellites. The other system is the Global Orbiting Navigational Satellite System (GLONASS).

Instrument approach procedure (IAP) – A series of predetermined manoeuvres by references to flight instruments with specified protection from obstacles to a point where a landing can be completed (if conditions are above the landing minima) or to a position clear of all obstacles (if conditions are below the landing minima).

Landing minima – Specified meteorological conditions of low ceiling (cloud), low visibility, thunderstorms, and strong winds (crosswind and tailwind). For the purposes of this analysis, in order for an aircraft to land at an aerodrome, the actual weather conditions need to be at or above each of the five landing minima.

- ***Landing visibility*** – The minimum allowable visibility for landing as stipulated by instrument approach procedures.
- ***Landing ceiling*** – The minimum ceiling for landing as stipulated by instrument approach procedures.
- ***Thunderstorms*** – The forecast presence or observation of thunderstorms overhead the aerodrome.
- ***Maximum demonstrated crosswind (crosswind)*** – The maximum crosswind an aircraft has been shown to land with during certification.
- ***Maximum tailwind (tailwind)*** – the maximum wind speed in the direction of landing (from behind the aircraft). Set at 10 knots for this analysis.

Likelihood – The probability based on historical observations of a nominated forecast comparison state. For example, for a given period the likelihood of an unprimed observation below the landing minima (unprimed observations) is calculated by dividing the time of unprimed observations by the total time in that period.

Observed conditions below landing minima – A weather event where the observed conditions were below the landing minima.

Primed observations below the landing minima (primed observations) – Observation of weather conditions below the landing minima preceded by a weather forecast (TAF or TTF) for conditions <u>below</u> the alternate minima (including forecasts both above and below the landing minima).

TAF (aerodrome forecast) – Weather forecast up to 9 km (5 NM) from an airport. For category A (international) airports like Adelaide, TAFs are released every 6 hours, and are valid for 24 or 30 hours. For category B (large) airports like Mildura, TAFs are released every 6 hours, and are valid for 12 or 18 hours.

Tailwind/downwind – The direction away from the source of wind.

TTF (trend forecast) – Short term weather forecast up to 9 km (5 NM) from major airports including Adelaide, but not Mildura. TTFs are valid for 3 hours from the time of release.

Unprimed aircraft arrivals – Expected aircraft arrivals during unprimed observations below the landing minima.

Unprimed observations below the landing minima (unprimed observations) – Observation of weather conditions below the landing minima preceded by a weather forecast (TAF or TTF) for conditions <u>above</u> the alternate minima.

Visibility – The horizontal distance that a black object can be seen against a bright background, or a calibrated light can be seen against an unlit background.

Weather episode – Any period *outside* of when both the forecast AND observed weather were above the landing minima (correct rejection). That is, a period of time where weather conditions at an aerodrome were either:

- forecast below the published alternate minima (for observed weather above or below the alternate minima), or
- observed below the published alternate minima (for forecast weather above or below the alternate minima).

Multiple events separated by weather conditions that were both forecast and observed above the landing minima by less than 1 hour were grouped into single *weather episode*. For example, if an observed period of weather below the alternate minima ceased, however, another was observed to occur within the hour, these two observations were be grouped into a single event with two periods below the minima.

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to operations involving the travelling public.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Australian Transport Safety Bureau

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Investigation

ATSB Transport Safety Report
Aviation Research Report
The effect of Australian aviation weather forecasts on aircraft operations: Adelaide and Mildura Airports, Australia
AR-2013-200
Final – 10 July 2017